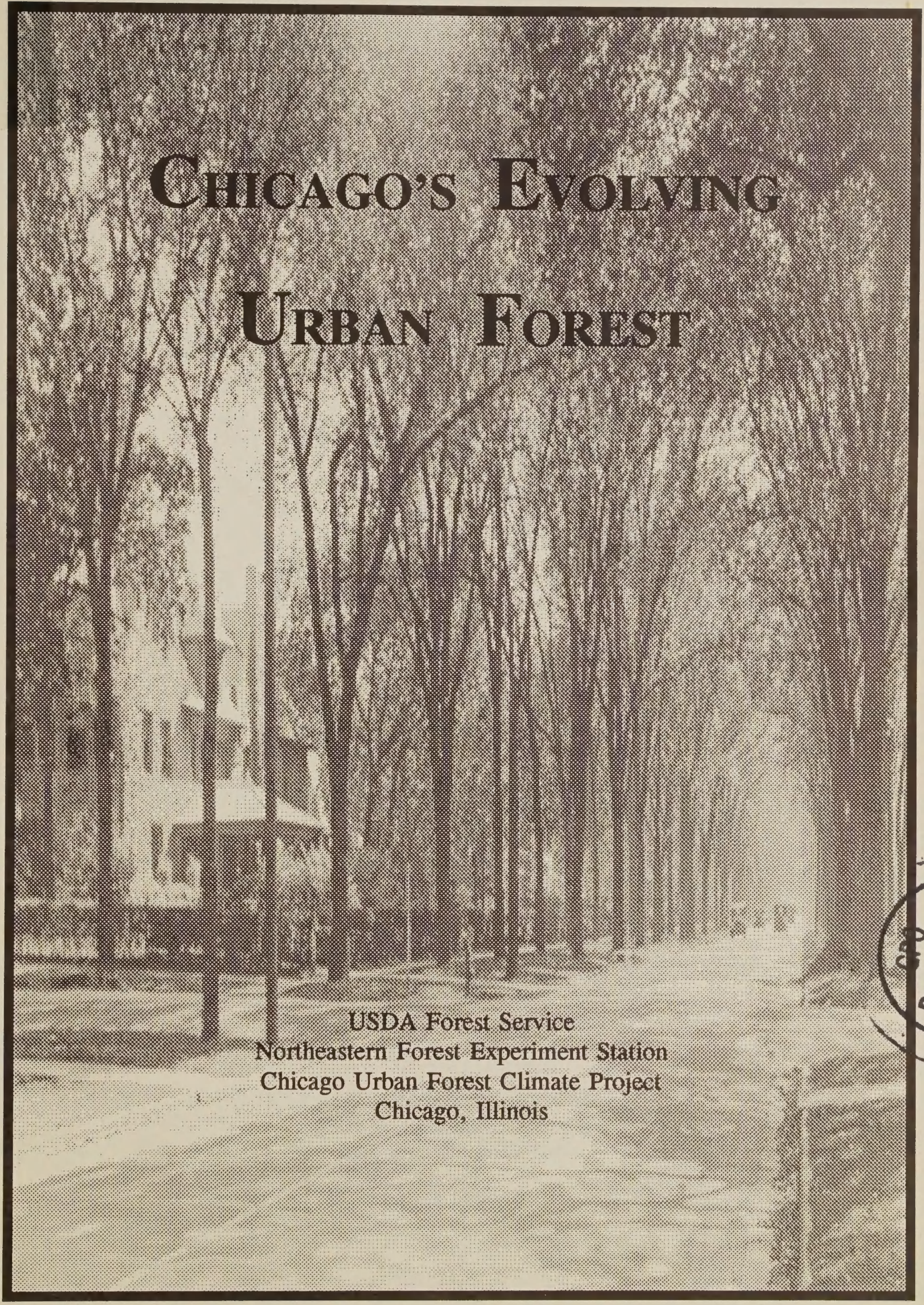
CHICAGO'S EVOLVING
URBAN FOREST
USDA Forest Service
Northeastern Forest Experiment Station
Chicago Urban Forest Climate Project
Chicago, Illinois

CHICAGO'S EVOLVING URBAN FOREST

AN INITIAL REPORT OF THE CHICAGO URBAN FOREST CLIMATE PROJECT

Principal Authors:
USDA Forest Service, Northeastern Forest Experiment Station

Dr. E. Gregory McPherson, Lead Scientist
Dr. David J. Nowak, Scientist
Paul L. Sacamano, Research Associate
Scott E. Prichard, Research Assistant

and
City of Chicago, Department of Environment

Edith M. Makra, Project Liaison

Dr. Rowan A. Rowntree, Project Leader
Urban Forest Ecology Research

Dr. Denver P. Burns, Station Director
Northeastern Forest Experiment Station

Chicago Urban Forest Climate Project
5801 N. Pulaski Rd., Bldg. C
Chicago, Illinois 60646

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EXECUTIVE SUMMARY

Chicago's urban forest has a rich history. The value of urban greenspace became evident when the first tree-lined boulevards and parks were developed in the 19th century. With the establishment of forest preserves in Cook and DuPage Counties, Chicago's urban forest evolved into an internationally acclaimed greenspace network. Today, over $100 million are spent annually to manage these public greenspace resources alone. In Chicago, Mayor Daley's GreenStreets program aims to preserve, plant, and maintain 500,000 trees. Over twenty communities in Cook and DuPage County have been designated as Tree City USAs. Despite this sizable investment and profound interest in urban forestry, many greenspace management questions remain unanswered. The Chicago Urban Forest Climate Project (CUFCP) was initiated to research some of these questions regarding the role of urban vegetation in environmental management. Findings will assist urban forestry programs to enhance environmental quality, energy efficiency, and civic beauty across the United States. The CUFCP study area consists of three sectors: Chicago, Cook County (exclusive of Chicago), and DuPage County (Fig. ES-1). Together, these sectors cover nearly 1,300 square miles and contain about 6 million people.

This initial report describes work completed during the first year of the three-year study, as well as plans for future research. To date, our research has been aimed at understanding the region's natural and cultural history, the evolution of its urban forest, and current policy, management, and environmental issues meriting urban forest research. This historical perspective provides a sound basis for developing solutions to problems of the present and future. New information about the scope and nature of the urban forest is also presented. The following text highlights our most significant findings.

AN URBAN FOREST LEGACY

During the past two centuries Chicago's landscape has been transformed from a mixture of prairie, wetlands, and oak-hickory forests into a major metropolis. Chicago's most enduring greenspace legacy is the Plan of Chicago, which was published by the Commercial Club in 1909. Today's greenbelt of forest preserves, tree-lined boulevards connecting large landscape parks, lakefront parks, and elevated railroads were all features of the Plan. Chicago's greenspace resources are enjoyed by millions of users daily, and are testaments to the visionary planning and leadership that have marked the region's history. Similarly, Prairie style landscapes first designed in Chicago by Dwight Perkins and Jens Jensen emphasized use of native plants and preservation of valuable natural landscapes. Their work inspired numerous prairie and forest restoration projects ongoing throughout the Midwest.

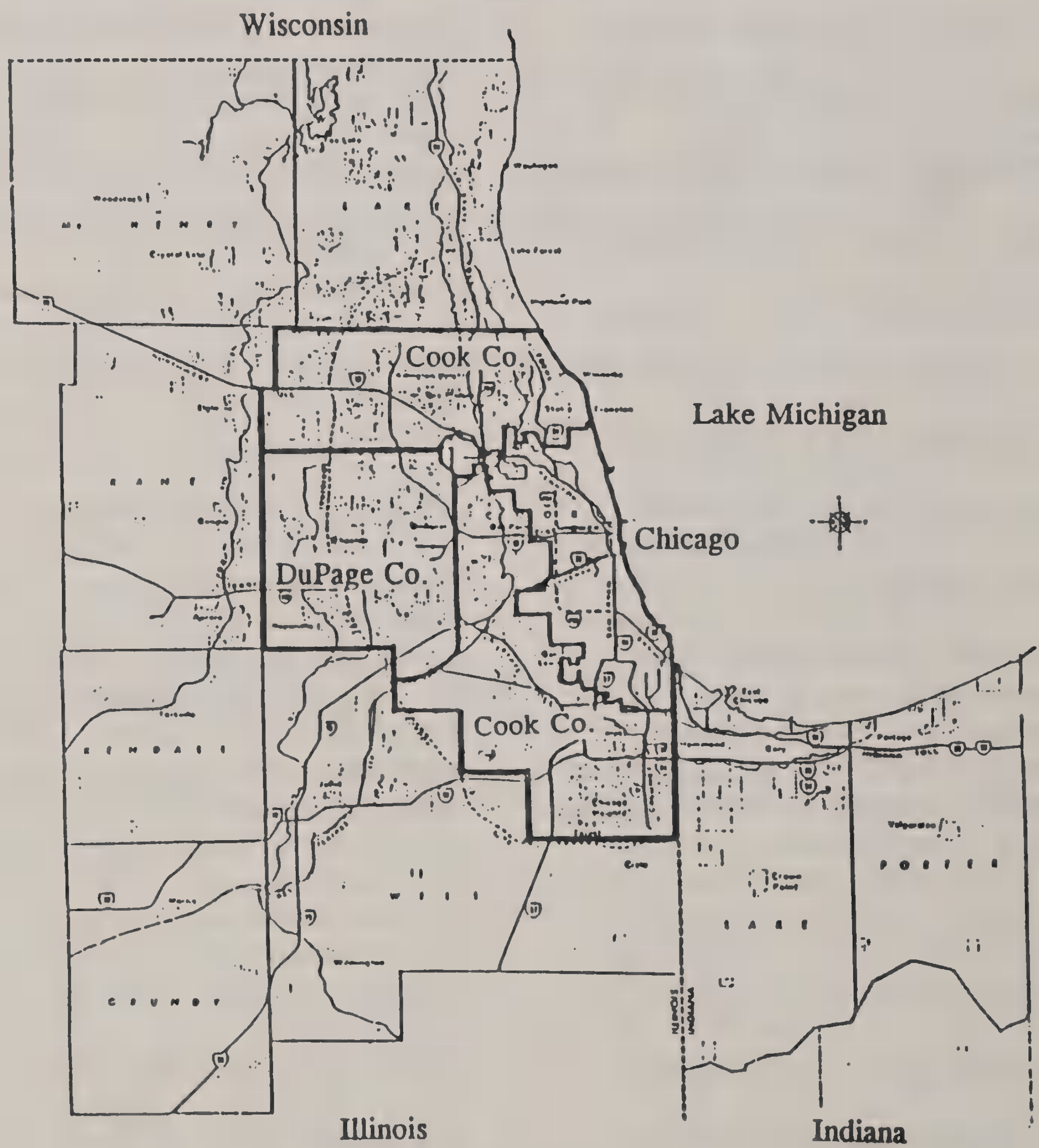

Figure ES-1. Chicago Urban Forest Climate Project study area includes the City of Chicago, Cook County, and DuPage County sectors.

URBAN FOREST MANAGEMENT

Urban forests in the Chicago area fall under the jurisdiction of many agencies and institutions. In Chicago, the Bureau of Forestry, Parks District, and GreenStreets are primarily responsible for planning and managing street and park trees. A new landscape ordinance mandates planting of parking lots and street trees following construction of large buildings. Many older suburban communities have well-funded, aggressive, state-of-the-art urban forestry programs. Complete street tree inventories, comprehensive Dutch elm disease control programs, and detailed street tree protection specifications are common management elements. Inadequate funding is the most limiting factor to the development of successful tree programs in other communities. More assistance to communities in the form of matching grants is becoming available through President Bush's America the Beautiful program and the Small Business Administration, both administrated by the Illinois Department of Conservation. Public knowledge and concern for the urban forest is quite widespread, largely due to numerous environmental education programs and advocacy groups in the Chicago area.

Urban forest management issues facing Chicago and suburban communities vary in scope and urgency. Because Chicago and older communities are densely developed, management focus is to provide regular tree care, increase tree stocking by planting existing greenspace, and create new greenspace by retrofitting trees into paved areas. Many older, less dense suburbs have extensive, maturing tree populations. Their challenge is maintaining the health and increasing the diversity of an older urban forest. The concerns of rapidly developing suburbs center mainly on the preservation of trees and include landscaping in new developments. Several communities are enacting ordinances to do so.

PATTERNS OF TREE COVER

Distribution of urban vegetation and land use types throughout the CUFCP study area were analyzed using aerial photographs. This analysis will be supplemented by field data collected during the summer of 1992. On average, tree cover for the study area has increased from a presettlement level of about 13 percent to nearly 20 percent today. Currently, tree cover ranges from about 11 percent in Chicago to almost 23 percent in Cook County (Table ES-1). Lower amounts of tree cover in Chicago reflect increased restrictions on trees imposed by the more densely developed surroundings. Available growing space (AGS is defined as potential planting space that is tree and grass covered) increases from only 38 percent in Chicago, to 67 and 75 percent in Cook and DuPage Counties, respectively. Canopy stocking levels (CSL is defined as the percentage of AGS covered by trees) range from 25 percent in DuPage County to 34 percent in Cook County. Greater tree stocking in Chicago and Cook County may be due to higher tree densities and/or more mature trees.

Table ES-1
Percentage Land Cover, Available Growing Space, and Canopy Stocking Level by Sector

Sector	Area (sq mi)	Tree	Grass	Bldg	Paved	Water	AGS	CSL
Chicago	237	11.1	26.9	27.4	32.4	2.2	38.0	29.2
Cook	722	22.5	44.7	12.6	18.2	1.9	67.2	33.5
DuPage	333	18.6	56.0	9.4	13.9	2.1	74.6	24.9
Total Study Area	1,292	19.4	44.4	14.5	19.7	2.0	63.8	30.4

The distribution of tree cover within each sector reflects underlying patterns of land use development (Fig. ES-2). Generally, tree cover is lower in intensively developed areas and greater in the less dense residential areas. CSL ranges from 20 to 40 percent for most land uses but is frequently below 20 percent in areas restrictive to tree growth, such as large commercial/industrial and transportation land uses. AGS ranges from 10 to 30 percent near the densely developed city centers, and 30 to 70 percent for moderately intensive land uses dispersed around the city (e.g., low density residential, education, transportation).

The relative importance of different types of tree cover vary with land use type and along an urban-rural gradient. For example, in land uses with moderate development intensity, the importance of street trees diminishes along the urban-rural gradient. In Chicago, street tree cover accounts for 50 percent of all tree cover in 1-3 family residential land uses, but drops to 19 percent in Cook County and 6 percent in DuPage County (Fig. ES-3). Most trees occurring in land uses of high or low development intensity are unmanaged, apparently "volunteers" along property edges, patches of relict forest, or other forms of opportunistic regeneration.

Urban forest management implications associated with these findings follow.

• In Chicago, where trees are most restricted by the built environment, street trees are the predominant type of tree cover. The potential for new tree plantings appears greatest in yards, highway right-of-ways, and large institutional and commercial/industrial lands. Field studies conducted during summer 1992 will determine the extent to which low stocking levels are due to planting restrictions from utilities, buildings, and lot configurations.

• In Cook County, lower stocking levels of street trees are compensated for by higher stocking levels of off-street managed trees. Park lands have surprisingly low canopy stocking levels and may be appropriate targets for new plantings.

• In DuPage County, stocking levels are relatively low but may increase as recent transplants mature. Management efforts should strive to continue

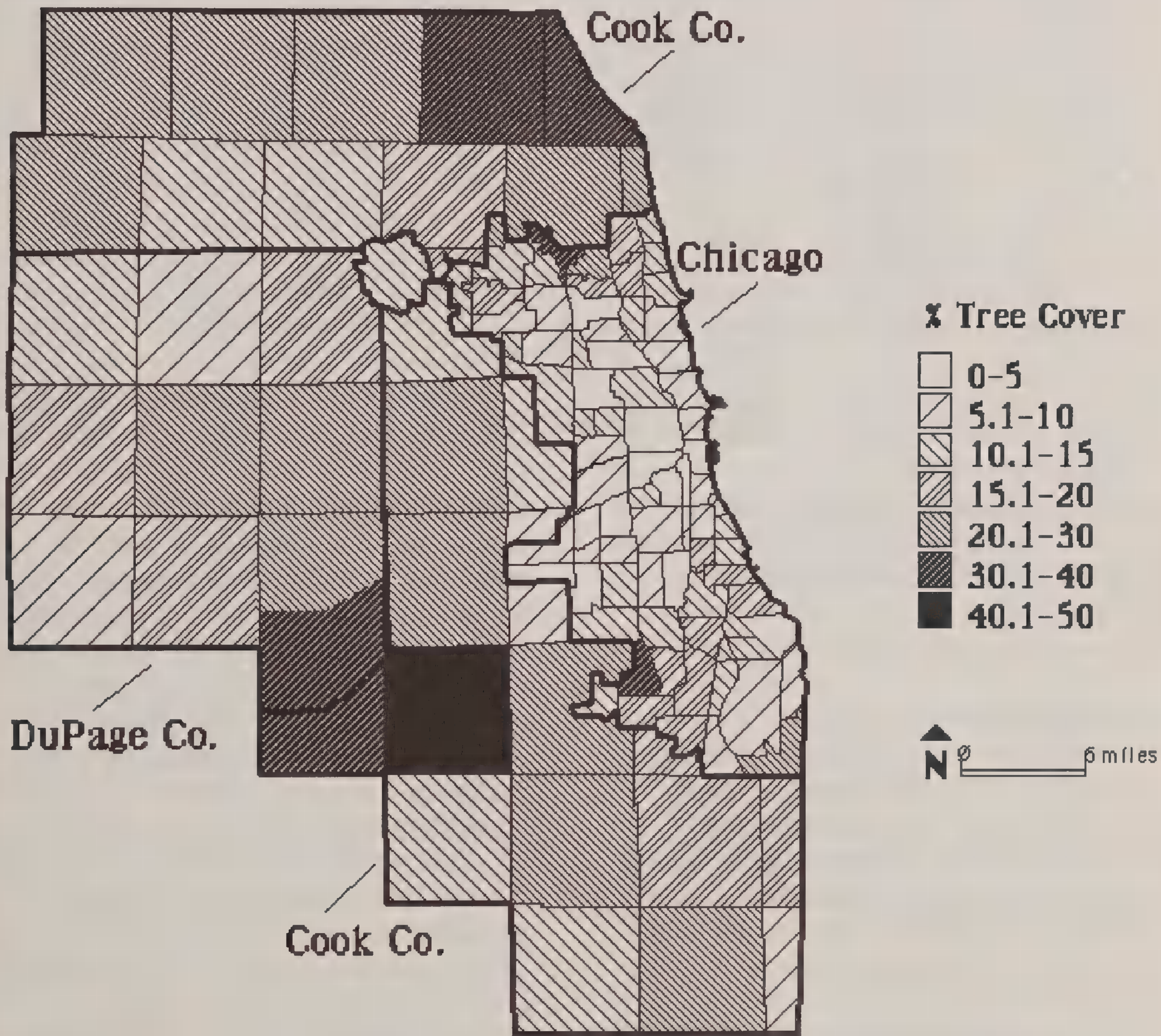

Figure ES-2. Tree cover by community area for all sectors.

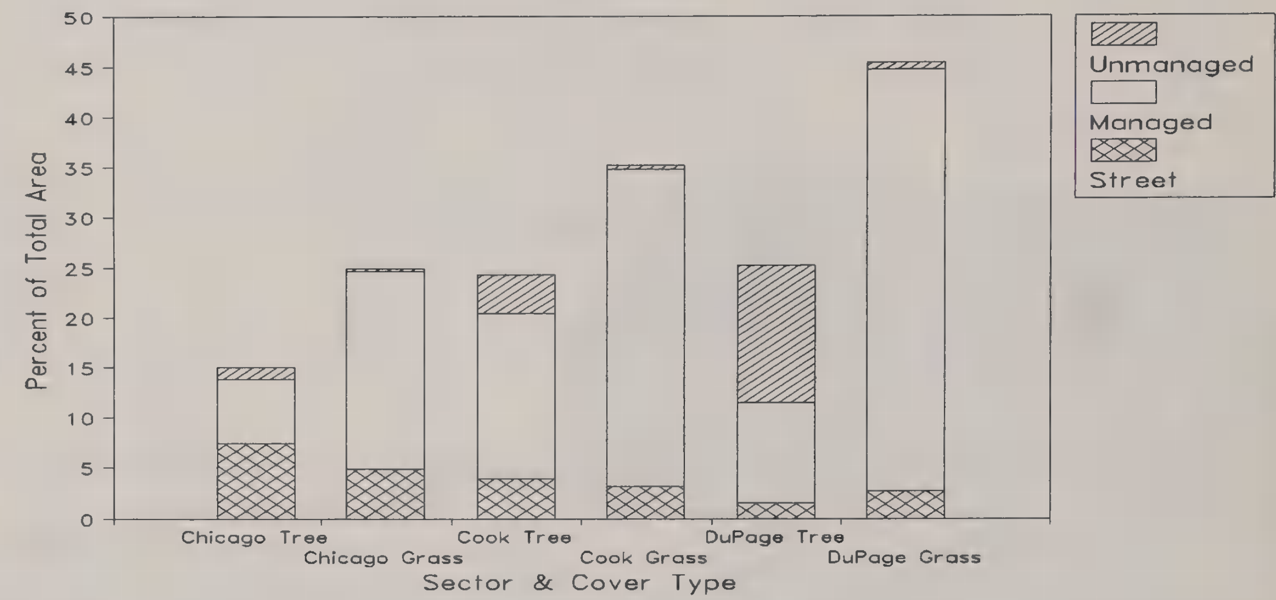

Figure ES-3. Vegetation cover for 1 to 3 family residential land.

preservation of existing forest, wetland, and other greenspace resources, as well as to increase tree cover on understocked land uses.

ENVIRONMENTAL ISSUES

Citizens everywhere are increasingly concerned about air and water quality and the long term availability of energy and water supplies. Policy makers, natural resource planners, and greenspace managers have recognized that urban vegetation can improve the quality of life in our cities.

Although air quality of the Chicago region has improved during the past two decades, unhealthy concentrations of pollution continue to occur. Ozone and particulate levels have exceeded federal health standards on 31 and 5 days from 1986 through 1990, respectively. Excessive levels of ozone generally occur on the hottest days during summer, when the urban heat island effect is strongest. A number of studies are currently being conducted locally to identify mechanisms of ozone formation, transport, and air pollution health risks. The potential of vegetation to intercept particulates and absorb various air pollutants in Chicago was initially demonstrated by analyzing a 525 acre site in lakefront Lincoln Park. Trees there may intercept up to 370 pounds of particulates daily, and absorb up to 163 pounds of carbon monoxide, 144 pounds of nitrogen oxides, and 2,573 pounds of sulfur dioxide. Using current air pollution control costs for these pollutants, the daily pollution abatement value of Lincoln Park's trees totaled $3,343.

Chicago's urban climate influences patterns of rainfall, energy use for heating and cooling buildings, and air quality.

Previous research on Chicago's urban heat island shows that 20 percent of the time, temperatures in August near Midway Airport were 5.4°F or more warmer than temperatures at Argonne National Laboratory, a rural site. Densely built urban areas store more heat and are slower to cool than rural areas. In Chicago, the cool, moist lake breezes can moderate urban warming for several miles inland from Lake Michigan.

One implication of Chicago's urban heat island is increased energy use for air conditioning. Despite a relatively short 4-month cooling season, more than 75 percent of the houses in the CUFCP study area are air conditioned. Approximately 15 percent of Commonwealth Edison's total residential electricity sales is for air conditioning. Overall, annual electricity consumption for air conditioning is projected to be 4.6 trillion watt hours, $405 million in sales. Results from computer simulations for three trees around a residential building in Chicago showed that shade alone reduced annual and peak cooling energy use by 31 percent (583 kWh) and 21 percent (0.67 kW), respectively. This annual savings amounts to about $70 per Chicago-area household with central air conditioning.

Potential heating energy savings from trees is also considerable because of the long heating season. More than 95 percent of the residential buildings in the study area are heated with natural gas, with average annual residential expenditures ranging from $592 for households in DuPage County to $755 in Chicago. More than $800 million (193 trillion cubic feet) are spent annually for natural gas to heat residential, commercial, and industrial buildings in the CUFCP study area. Computer simulations and measurements indicate that windbreak plantings around unprotected homes can reduce annual heating costs by 10 to 30 percent. Assuming a 15 percent reduction due to vegetation, an annual savings of $83 (167 therms) is possible for well-landscaped residences in Chicago.

Urban-induced increases in rainfall have been observed in Chicago and several other Midwestern cities. The cause of increased rainfall in and downwind of urban areas has not been fully explained, but is partially due to greater amounts of small particles in the city compared to surrounding rural areas. These particles serve as condensation nuclei around which raindrops form. Historical studies indicate that Chicago receives about 15 percent more rainfall in the summer than would occur without the city. There are more heavy rain events and more rainfall per heavy rain event in the city than surrounding rural areas. These urban-induced increases in rainfall are responsible for 10 to 100 percent more flooding events in urban areas than in rural areas. The Chicago area is prone to flooding due to poorly draining soils, little topographic relief, and old sewer systems that overflow during heavy rainfall events. Local stormwater management approaches range from the highly technological Tunnel and Reservoir Project to the traditional solutions of inlet controls, retention/detention basins, and ordinances. Urban greenspace can help regulate the flow of water through cities by reducing the volume and slowing the rate of overland flow. Tree

crowns intercept and store rainfall, while soil also stores moisture. Although these processes are unlikely to substantially reduce peak flows, they can reduce initial flow volumes and rates.

CUFCP RESEARCH GOALS

Chicago's urban greenspace cools the city, cleans the air, conserves energy, limits carbon dioxide emissions, and reduces stormwater runoff and flooding. It provides many other benefits as well, such as opportunities for recreation and relaxation, wildlife habitat, increased property values, nature education, and more attractive streets, parks, and neighborhoods. However, there is a substantial potential for increasing all these benefits.

The Chicago Urban Forest Climate Project's goal is to develop information that greenspace managers, natural resource planners, utilities, and residents can use to obtain more benefit from their investment in Chicago's urban forest. Specific objectives of the CUFCP are to:

1) Enhance our understanding of relations between urban greenspace and other aspects of Chicago's physical environment including its hydroclimate, air quality, energy use, and carbon cycling.

2) Determine the net benefits of greenspace by translating selected environmental benefits into dollar terms and accounting for vegetation management costs.

3) Produce greenspace management recommendations that demonstrate how the selection, location, planting, and management of trees and other greenspace resources can maximize net environmental benefits.

4) Develop new approaches for understanding urban forest structure and function that can be applied in other communities across the United States.

CUFCP analyses and recommendations will be conducted at two scales: regional and neighborhood. Regional findings regarding the effects of existing vegetation and proposed future plantings on air quality, carbon dioxide, and other benefits and costs will be presented for Chicago, Cook County, and DuPage County. These findings are likely to be of most value to policy-makers, regional planners, municipal/county greenspace managers, and other researchers dealing with regional air, water, and energy issues.

Research at the neighborhood scale will seek to better understand relations between greenspace and neighborhood hydroclimates, energy use patterns, air quality, and carbon cycling by studying one or more residential neighborhoods in detail. Findings from neighborhood scale research will particularly interest local utilities (e.g., electric, water, natural gas), landscape professionals, and homeowners.

Detailed study plans for each of the proposed research topics listed below have been developed by CUFCP scientists.

- Determining urban forest structure using aerial photographs and ground surveys.

- Demonstrating use of airborne videography for determining urban forest structure and health.

- Urban tree leaf area, leaf biomass, and growth rates.

- Urban hydroclimatological flux study: measurement and modeling.

- Predicting urban forest effects on the sub-canopy microclimate.

- Modeling urban forest effects on building energy use.

- Modeling urban forest effects on atmospheric pollutants.

- Modeling urban forest effects on atmospheric carbon dioxide.

- Modeling benefits and costs of urban forest plantings and management.

The CUFCP presents a unique opportunity to focus research expertise on the role of urban forests in environmental management. The proposed research is comprehensive, ranging from studying the leaf area of individual trees to the aggregate effects of all trees on air quality. Although the scope of research may deviate in response to changes in personnel and funding, the CUFCP will generate new information to benefit those who manage and live in our urban forests.

1 INTRODUCTION

This report describes work completed during the first year of the 3-year Chicago Urban Forest Climate Project (CUFCP). It compiles information on the region's natural history, changes in the urban forest resource, and current management. The report also addresses relationships between the urban forest and environmental issues such as air quality (including greenhouse gases), energy consumption and conservation, and urban hydrology. New findings about the extent of urban forest cover throughout the Chicago region are presented.

The impetus for the CUFCP came in 1990 when Mayor Richard M. Daley expressed a desire for urban forest research in support of his comprehensive plan for greening Chicago, called GreenStreets. In 1991, Congress appropriated funding to the USDA Forest Service for the project. The CUFCP is led by scientists from the USDA Forest Service's Northeastern Forest Experiment Station in cooperation with scientists from local universities. A number of departments within the City of Chicago are supporting the project, including the Mayor's Office, Department of Environment, Department of Streets and Sanitations' Bureau of Forestry, and the Planning Department. Other organizations contributing to the CUFCP include the Chicago Park District, Northern Illinois Planning Commission, DuPage County, Cook County, DuPage and Cook County Forest Preserves, Metropolitan Water Reclamation District of Greater Chicago, Commonwealth Edison, Peoples Gas, Northern Illinois Gas, Illinois Environmental Protection Agency, Lake Michigan Air Director's Consortium, and the Open Lands Project.

The goal of the CUFCP is to develop information that can be used by policy makers, greenspace managers, natural resource planners, utilities, and residents to obtain maximum benefit from their investment in Chicago's urban forest. Specifically, the project aims to enhance our understanding of urban forest effects on hydroclimate, air quality, energy use, and carbon cycling in the Chicago region. Results from the study will be used to describe the potential of different urban forest management strategies to maximize immediate and long-term environmental benefits. Many of these recommendations, as well as the methodologies and models upon which they are based, will be useful to those concerned with enhancing environmental quality in cities throughout the United States.

The CUFCP study area (Cook and DuPage Counties) covers 1,292 square miles (3,346 square kilometers) and contains nearly 6 million people (Table 1). For study purposes it has been subdivided into three sectors: City of Chicago, Cook County, and DuPage County (Fig. 1). The City of Chicago accounts for 18 percent of the entire study area and 47 percent of the total population, making it the most densely populated sector. Cook County, exclusive of Chicago, contains

Table 1
Geographic Information on CUFCP Sectors

Sector	Area (sq mi)	percent of total	Population in 1990 (millions)	percent of total	Population density (no./acre)
Chicago	237	18	2.78	47	18.4
Cook County	722	56	2.32	40	5.0
DuPage County	333	26	0.78	13	3.7
Total	1,292		5.88		7.1

more than half of the study area and many of Chicagoland's older suburban communities. For this report, future reference to the Cook County sector assumes exclusion of Chicago. DuPage County is the most rapidly urbanizing sector within the study area.

Chicago's urban forest has a rich history. The value of trees and parks to Chicagoans has been evident since the 19th Century when the first parks and tree lined boulevards were developed. Interest in regional greenspace continued with the establishment of the Tree Planting Society in 1904, The Plan of Chicago, and forest preserve districts in Cook and DuPage Counties. The region's urban forest had evolved into an internationally acclaimed greenspace network. Today, more than $100 million are spent annually to manage these greenspaces. The amount of money spent to manage Chicago's urban forest indicates its large social value. On an average per-acre basis, Chicagoans invest about $1,000 yearly for the management of parks, street trees, and forest preserves. By contrast, fewer than $7 per acre are appropriated to manage exurban forest land in the United States' 156 national forests. Despite this large investment, many questions about greenspace management in Chicago and in other cities remain unanswered. This report addresses some of these questions and presents a research plan to locate the answers.

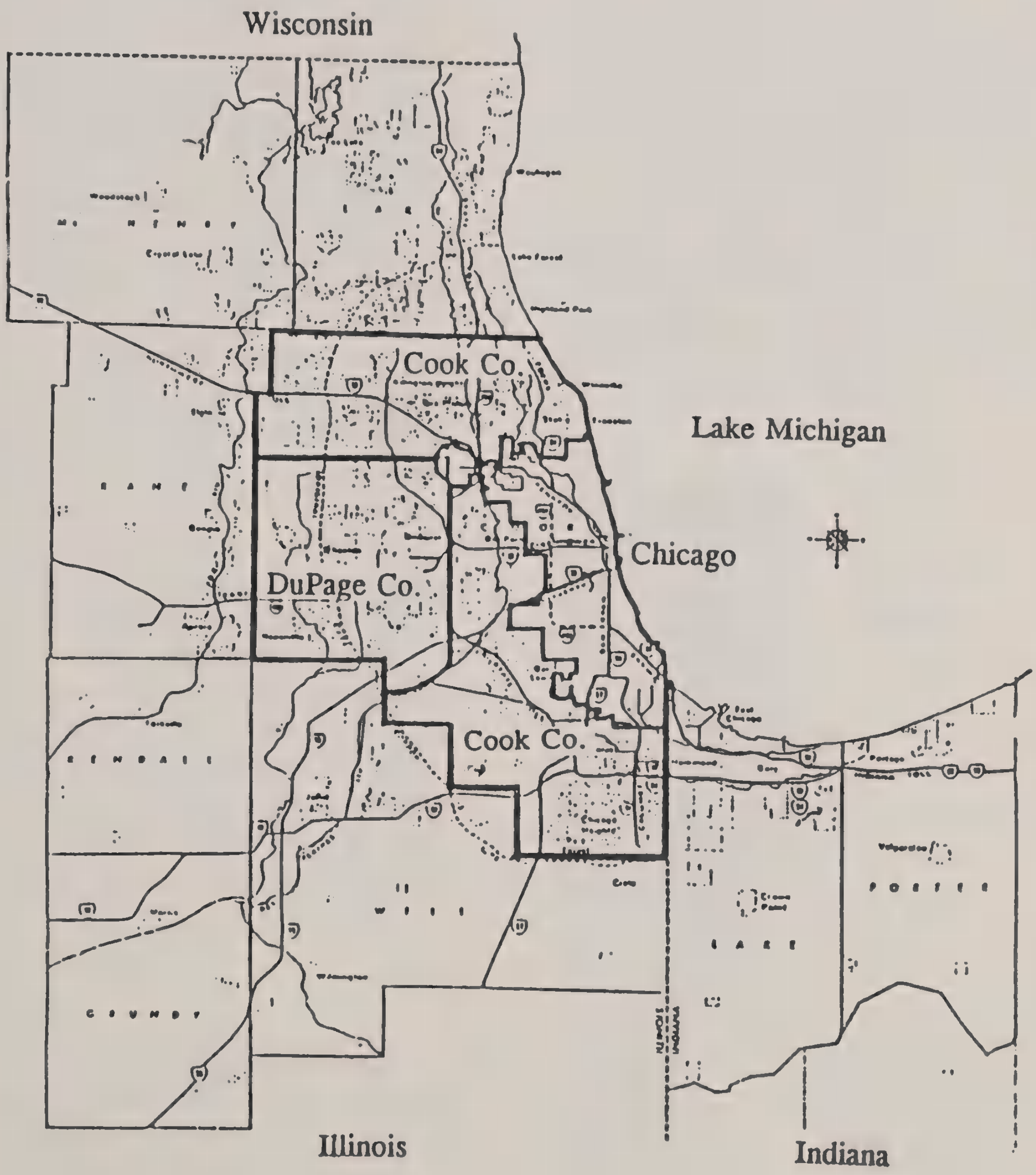

Figure 1. Chicago Urban Forest Climate Project study area includes the City of Chicago, Cook County, and DuPage County sectors.

2 NATURAL HISTORY

Since the 1770's, when Chicago's first permanent settlement was established, the region's landscape has been altered radically. Urbanization changed the face of the region, rerouting streams, covering soils with paving, reducing and fragmenting wildlife habitat, and altering local climates. However, examples of Chicago's presettlement landscape still can be observed at places such as Harms Wood and Markham Prairie. These relicts serve as guideposts for current ecological restoration projects and are important reminders of how this region looked for centuries preceding Euro-American settlement.

Chicago's urban forest today is a result of the region's natural history, expressed as what vegetation grew here prior to settlement, and changes to habitat wrought by humans during the process of urbanization. The following section describes aspects of Chicago's geomorphology, hydrology, soils, vegetation, and climate that have had an enduring effect on its landscape.

GEOMORPHOLOGY

The origin of the northeastern Illinois landscape is most closely associated with the Pleistocene ice event which occurred 10,000 to 15,000 years ago (Schmid, 1975). The Laurentide Ice Sheet, part of the Pleistocene ice age, covered a large portion of Canada and the Northern United States and is directly responsible for the gently rolling terrain, drainage patterns, and parent material from which present-day soil types are derived. The retreat of the Laurentide Ice Sheet left behind moraines (masses of boulders, sand, gravel, and clay) that inundate northeastern Illinois. The Valparaiso Moraine (Fig. 2), is responsible for the creation of Glacial Lake Chicago which once covered much of Cook and DuPage Counties (Schmid, 1975). This moraine also led to the formation of the Chicago River.

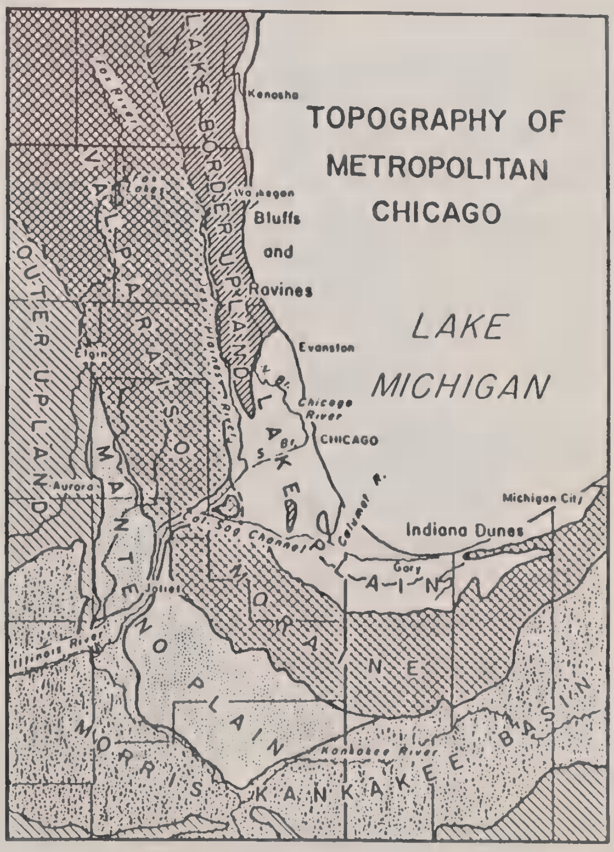

Figure 2. Topography of Chicago Region (From Platt, 1971).

The terrain of northeastern Illinois is relatively flat, with an elevation ranging from 580 feet (177 meters) along Lake Michigan to about 900 feet (274 meters) on the Valparaiso Moraine in DuPage and western Cook Counties (Schmid, 1975).

Urbanization is a more recent major factor influencing the landscape of northeastern Illinois. Urbanization has altered presettlement natural conditions once found in the region. Both glaciation and urbanization have influenced and continue to affect the hydrologic cycle, soil types, and vegetation of the Chicago area.

HYDROLOGY

The drainage pattern of northeastern Illinois is as unusual as it complex. The Valparaiso Moraine acts as a natural drainage divide that has created two drainage basins. Water to the east of the moraine drains to the Great Lakes system while water to the west of the moraine drains to the Mississippi River system via the Fox, Des Plaines, and Kankakee River systems. Several shorter rivers, such as the Chicago and Calumet, have penetrated the morainal system and flow toward Lake Michigan. Around the turn of the century, the flow of the Calumet and Chicago Rivers was reversed from Lake Michigan to increase sanitation and facilitate disease control.

The relatively flat terrain of northeastern Illinois has created slow-flowing river systems. As a result, a large number of pumping stations is needed to expedite stormwater runoff and sewage disposal (Cutler, 1976). Artificial hydrologic systems such as the Northshore Sanitary Canal and the Cal-Sag Channel also are used for stormwater runoff from inland communities. Along with the flat terrain are layers of impermeable clay that lead to significant flooding throughout the area.

Potable water for Chicago residents is pumped from Lake Michigan. Three major underground aquifers currently are used to supply suburban water demands. One open aquifer is composed of gravel and sand deposits that act as reservoirs. Two closed aquifers are a shallow Dolomite layer aquifer and a deep Sandstone layer aquifer (Mapes, 1979). The open aquifer is recharged by annual precipitation while the closed aquifers are recharged by infiltration of stormwater along the border of northern Wisconsin and Minnesota. Recently, declining water tables and ground-water pollution in areas that rely on ground water have created a demand for Lake Michigan water.

SOILS

The bedrock of the Chicago area is primarily of Silurian age Dolomite ranging in thickness from 3 to 200 feet (0.9 to 61 meters) (Mapes, 1979). The soils found in the area are among the most productive in the world. The soil parent material found in Cook and DuPage Counties is primarily outwash (material deposited by glacial water), glacial till (material deposited by glacial ice), and loess (silty wind deposit) (Fehrenbacher et al., 1967).

Four soil orders are found in northeastern Illinois. Two major soil orders present are the Mollisols and Alfasols. Mollisols are closely associated with prairie vegetation while Alfasols are associated

with forest vegetation. Two minor soil orders in the area are Enceptisols and Histolsols (Fehrenbacher et al., 1967).

Soils in Cook and DuPage Counties vary in texture. Silt and loam soils are found primarily along major streams: silt soils primarily along western uplands, sand and loam soils confined primarily to areas within Chicago, and silt and clay soils predominating through most of the two counties. The soil base throughout the area ranges between 1 inch and 100 feet (2.54 centimeters to 30 meters) (Fehrenbacher et al., 1967).

Displacement and disturbances due to urbanization and agriculture have altered many local soils. Housing construction practices have included the wholesale movement of soil from new construction sites. Sand and gravel mining has moved and disrupted local soils. Agricultural practices have affected soils by creating an environment for large-scale erosion by wind and water.

Urban soils generally have great vertical and spatial variability. Considering this variability and that soils greatly affect tree health and growth, tree managers in urban areas must be aware of site-specific soils. In general, Chicago's urban soils have a modified soil structure leading to compaction; a surface crust on bare soil that usually is water repellent; a modified soil reaction, usually elevated; restricted aeration and water drainage; interrupted nutrient cycling and modified soil organism activity; anthropeic materials and other contaminants; and modified soil-temperature regimes (Craul, 1985). These factors often lead to difficulty in growing and managing trees.

VEGETATION

The presettlement vegetation of northeastern Illinois was predominantly bluestem prairie (*Andropogon* spp., *Panicum* spp., *Sorghastrum* spp.) and oak-hickory forest (*Quercus* spp., *Carya* spp.)(Kuchler, 1969). In 1820, approximately 13 percent of Cook County and 14 percent of DuPage County was covered with trees (Iverson and Joselyn, 1990). Figure 3 illustrates tree cover in 1840.

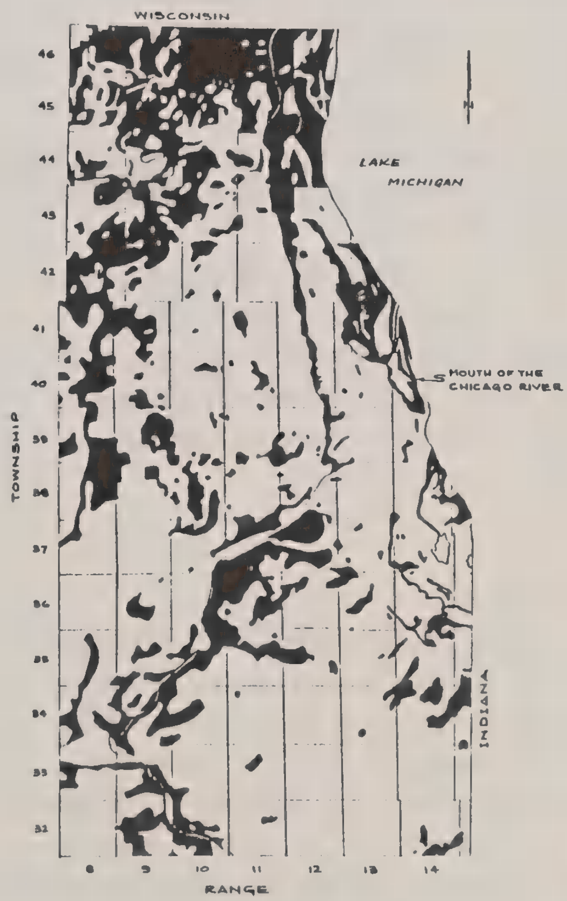

Figure 3. Distribution of forest (black) and prairie (white) in Chicago region during the 1840's (From Schmid, 1975).

Bur oak (*Quercus macrocarpa*) typically dominated on beachridges along with white oak (*Q. alba*), Hill's oak (*Q. ellipsoidales*), red oak (*Q. rubra*), and black oak (*Q. velutina*). Swamp forests were commonly composed of swamp white oak (*Q. bicolor*), bur, red, and white oaks along with ashes (*Fraxinus* spp.) and elms (*Ulmus americana*, *U. fulva*). On the moraine, forests were composed of bur, red, white, swamp white, and Hill's oaks along with shagbark hickory (*Carya ovata*) and ironwood (*Ostrya virginiana*). On more mesic sites, sugar maple (*Acer saccharum*) and basswood (*Tilia americana*) became prominent. Beech (*Fagus americana*) was found only in the immediate vicinity of Lake Michigan (Schmid, 1975).

Due to plant introductions associated with urbanization, Cook County now contains about 245 woody species, compared with about 180 woody species in DuPage County(Iverson and Joselyn, 1990).

CLIMATE

The climate of northeastern Illinois is most closely associated with a moist mid-continental type with extreme variation in temperature and precipitation throughout the year. This region is affected by moist tropical air masses from the Gulf of Mexico during the summer months and cold polar air masses from the northwest in the winter months.

Precipitation is at a maximum during the summer months due to invading maritime tropical air masses that often move along cold fronts (Fig. 4). Precipitation averages about 34 inches (86.36 centimeters) per year, droughts and long rainy periods are rare (Cutler, 1976). Thunderstorms are common in the summer months. Sunshine is most frequent during late summer months (Fig. 5).

Average monthly temperatures range from 26°F (-3.3°C) in January to about 75°F (23.9°C) in July, with a annual average of about 50°F (10°C) (Fig. 6). Extreme temperatures of -27°F (-33°C) and 104°F (40°C) have been recorded. The moderating effect of Lake Michigan helps cool lakeshore areas in summer and warm them in winter. This temperature variation is about 2 to 5°F (1.1° to 2.8°C) (Cutler, 1976).

Northeastern Illinois averages 183 consecutive frost-free days a year. Although Chicago is called the "Windy City," its average windspeed is 10.3 mph (16.6 km/hr), placing it 81st on a list of 270 U.S. cities. Chicago's windiest period is January through April (Fig. 7).

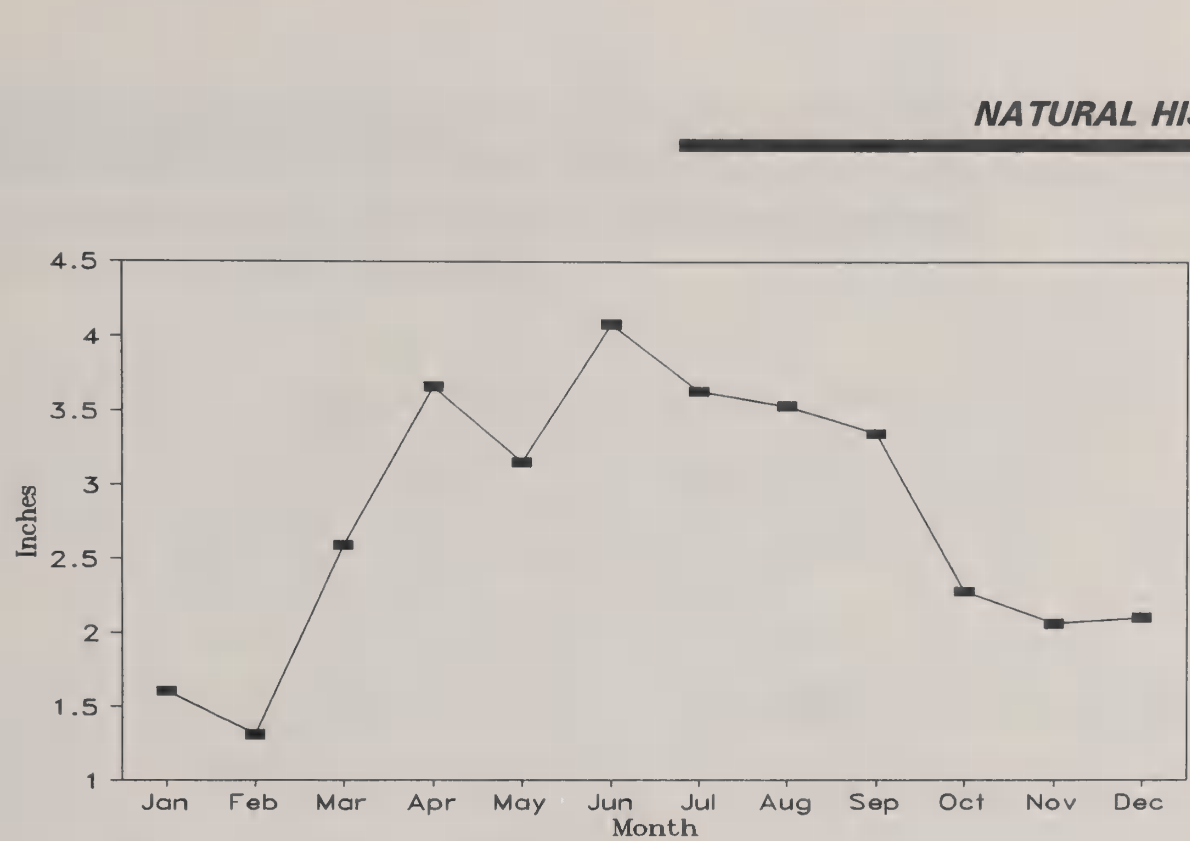

Figure 4. Monthly normal precipitation in Chicago, 1951-80 (NOAA, 1989).

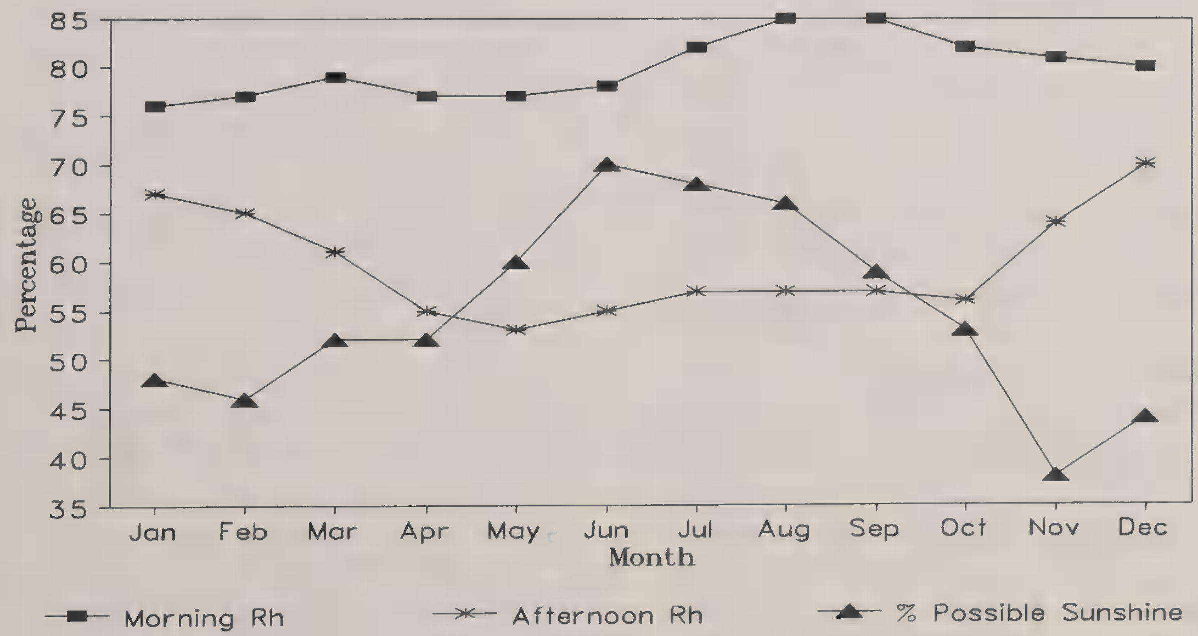

Figure 5. Monthly average relative humidity (1958-89) and percent of possible sunshine hours (1981-89) in Chicago, (NOAA, 1989).

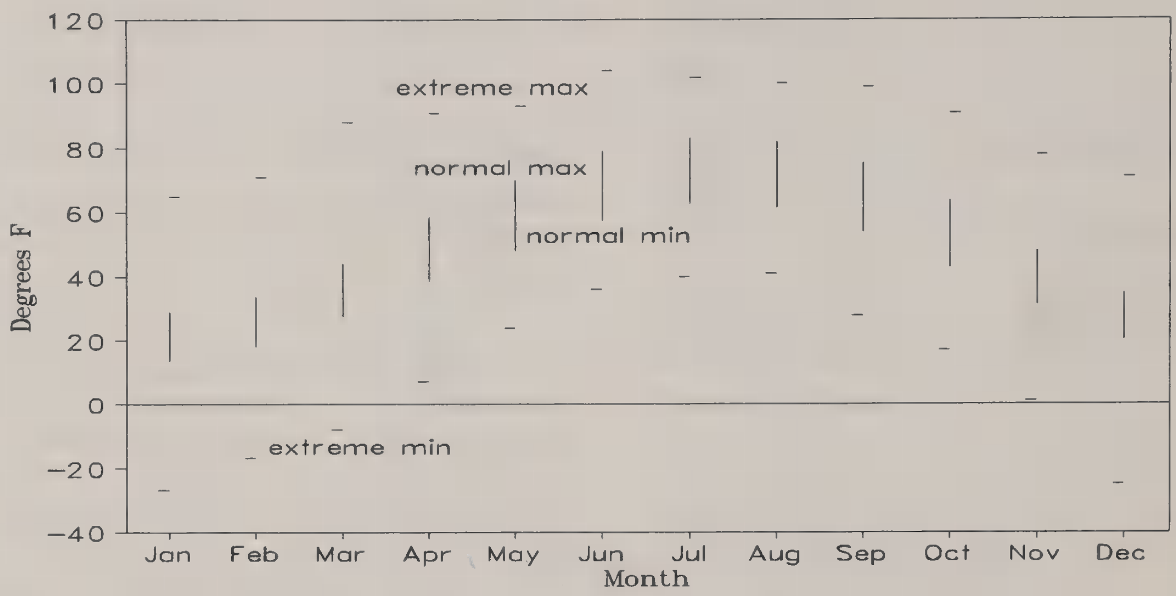

Figure 6. Normal daily maximum and minimum temperatures (1951-1980) and extreme daily maximum and minimum temperatures (1958-1989) in Chicago, (NOAA, 1989).

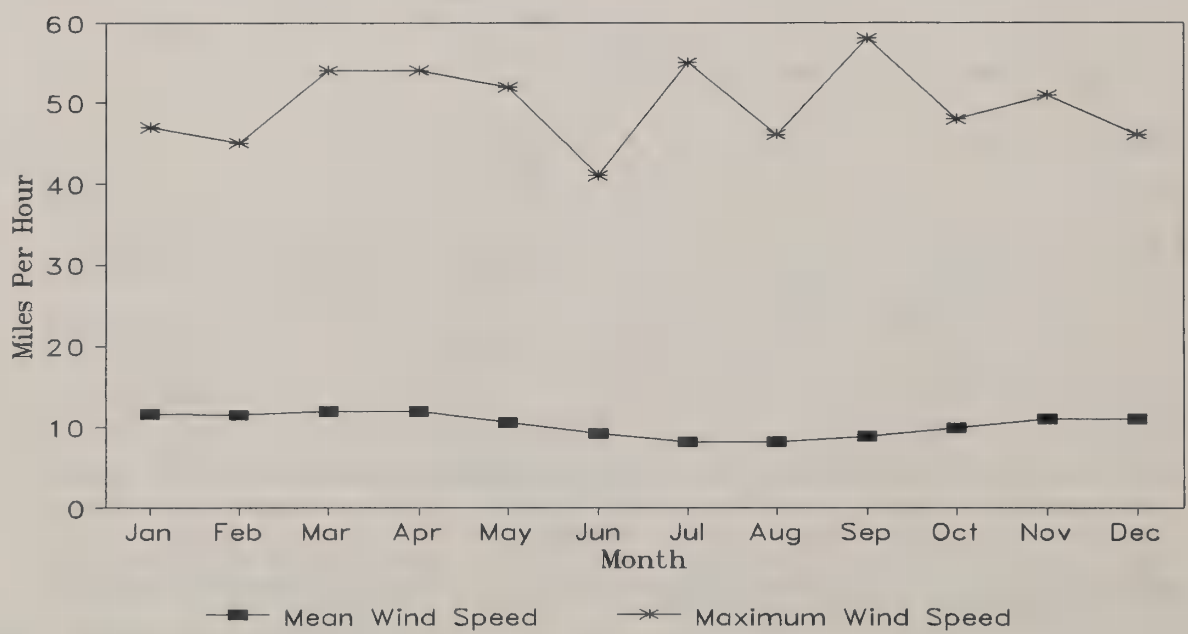

Figure 7. Monthly average and maximum windspeed in Chicago, 1958-89 (NOAA, 1989).

3 URBAN FOREST HISTORY

The structure of Chicago's urban form and specifically its urban forest is attributed first to the region's natural history and more recently to the social processes that direct land use and development. The following section provides an overview of Chicago's growth, focusing on metropolitan greenspace. Initial settlement and expansion of the city are described, the role of urban planning and policy in shaping open space is discussed, and characteristics of public and private landscapes are reviewed.

INITIAL DEVELOPMENT

The overall structure of greenspace is controlled by urban patterns of land use and development. The structural arrangements of urban land use patterns are explained by three accepted generalizations (King and Golledge, 1978). Cities are commonly aggregated in zones around a central business district of commercial, cultural, and civic activity. Radiating from the core are wedges of residential and other districts developing like spokes of a wheel along transportation corridors. In some instances, additional centers of activity originate outside of the central business district, often along transportation routes, and affect land use patterns. Evidence of each of these forms is seen in the Chicago region (Fellmann, 1957).

Transportation corridors have had a key role in creating regional land use and development patterns. Specifically, the growth of Chicago and its suburban communities has been closely linked to progress in transportation technology beginning with shipping, followed by rail, the auto, and the airplane.

The City

The word "Chicago" often is interpreted from indigenous dialects as meaning wild onion, but also may refer to the river systems extending south and west of Lake Michigan (Schick, 1891). These rivers have been important to the initial settlement of Chicago and are credited with attracting the first Europeans to the region.

As early as the 17^{th} century, the French and Canadians passed through the area around the mouth of the Chicago River after exploring the Mississippi Valley. The first settlers used the extensive waterways as travel and trade routes (Fig. 8). However, not until a treaty with Indians in 1835 brought peace to the region did the tide of settlement begin. Chicago was incorporated 2 years later with a population of 4,000 and an area of 10 square miles (26 square kilometers) (Cutler, 1976).

The portage between the Chicago and Des Plaines Rivers made possible a connection from the Atlantic Ocean through the Great Lakes to the Mississippi and eventually the Gulf of Mexico. This stimulated Chicago's evolution into a center of trade and commerce for land speculators, settlers, and pioneers continuing into the Northwest Territories. One

Figure 8. Chicago River and first permanent settler, Jean Baptiste Point du Sable (Photo courtesy of Chicago Historical Society).

year after incorporation, the city's population had increased fivefold.

The city originally was laid out at the forks of the Chicago River by the commissioners of the Illinois and Michigan Canal. In 1848, the canal was completed along the Chicago and Des Plaines Rivers to facilitate the navigation of larger vessels to the Mississippi. More earth was removed for this canal than for the construction of the Panama Canal (Fellmann, 1957). Speculation over its economic impact stimulated growth along the canal route adjacent to the South Branch Chicago River.

Other improvements in transportation facilities and services helped Chicago become one of the most important cities in the world. By the 1850's, nearly all rail lines entering the west converged in Chicago, making access to the surrounding fertile agricultural lands easier (Cutler, 1976). During this period, horse railways and plank roads over wet prairie lands were constructed, followed by elevated rail and cable car lines (Fellmann, 1957).

Roads and transportation routes often were developed along section lines of the General Land Survey (ie., Roosevelt Road, North and Western Avenues, and Pulaski Road) (Fig. 9). Deviations from

Figure 9. Chicago in 1857 with rectilinear grid, diagonal streets, and railroad visible (Photo courtesy of Chicago Historical Society).

the rectilinear grid follow well drained ancient beach ridges that were old Indian trails and include N. Clark St., Ridge Ave., Rogers Ave., and Vincennes Ave..

The Suburbs

Rail lines radiating from the central business district made possible the growth of satellite communities. Some of the first of these were in Cook and DuPage Counties and became home to wealthier Chicagoans escaping the pollution and overcrowding typical of industrial centers at the turn of the century. After the great Chicago fire in 1871 burned most of the area east of the branches of the Chicago River, the city center added more commercial land uses as wealthy residents relocated to the suburbs (Mayer and Wade, 1969).

Two communities outside of the city, Riverside and Evanston, were noted for their sensitivity to important landscape features. Evanston attracted prosperous Chicago businessmen. The area was "...wisely platted with reference to existing beauties of landscape..." and its streets were "...thickly studded with trees and shrubs" (Schick, 1891, p. 417) (Fig. 10).

Likewise, Riverside, designed by Frederick Law Olmsted and Calvert Vaux in 1868, was platted in a parklike way.

Figure 10. Sheridan Road in Evanston, 1920's (Photo courtesy of Chicago Historical Society).

"Residences are separated by patches of the untouched original forest" (Schick, 1891, p. 417). Large lots, extensive setbacks, and curvilinear divided roads made Riverside distinctive from other communities. Newer tract development and planned communities continue to resist the rigid grid layout common to the city.

While Chicago had nearly reached its present size in terms of area and seen its population peak by 1950, suburban growth stimulated after World War II continues (Fig. 11). With the arrival of the automobile, roads were built that provided an alternative to commuting to Chicago by rail. This prompted the development of land between the rail lines (Miller, 1962). Some of these routes, including US 30, 6, and 20, also follow old beach ridges while US 57 traverses the old Indian Boundary line of land ceded to the United States by Native Americans (Mayer and Wade, 1969).

Progress in transportation services and facilities and cheaper land have drawn commercial and manufacturing activity from the city's central district. Regional shopping centers have located near expressways in suburban communities, while heavy industry has moved to a secondary nucleus on Chicago's south side (King and Golledge, 1978). More recently, high technology industries have been attracted to the north and west suburbs expanding

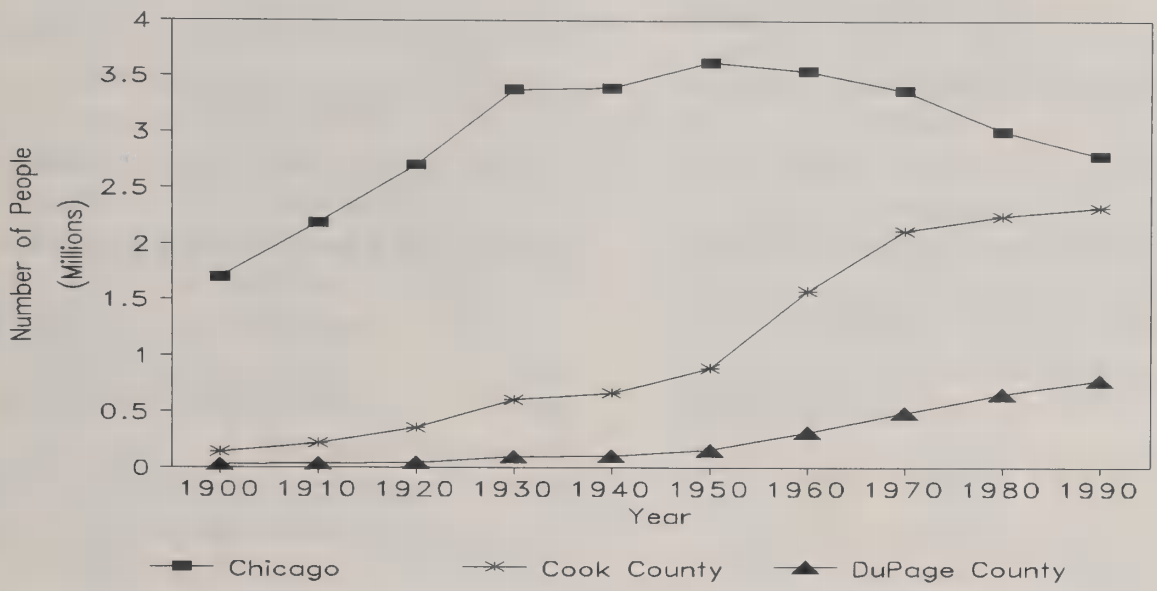

Figure 11. Population change from 1900 to 1990 in Chicago, Cook County excluding Chicago, and DuPage County.

the Research Development Corridor along Interstate 88.

Today, with OHare and Midway Airports, the Chicago metropolitan area has one of the most multilayered transportation networks in the world (Cutler, 1976).

CITY & REGIONAL PLANNING

There have been important efforts to promote the development and quality of life of Chicago-area residents through the years. Late 19th and early 20th century advocates of progressive reform used urban nature to improve the physical, mental, and spiritual well-being of city dwellers. Directly linked to these efforts was the evolution of parks, forest preserves, and specific plans to guide Chicago's growth and maintain greenspace as a community asset.

Progressive Reform

Poor conditions that plagued city dwellers provided much of the impetus for the flight to the suburbs during the late 19th century. Rapid growth and industrialization of the city that was largely unplanned for had caused significant air and water pollution, overcrowding, and consequent unsanitary living conditions. Untreated sewage was discharged into the Chicago River, which emptied into Lake Michigan, the city's source of potable water. Widespread disease prompted the construction of the Chicago Sanitary and Ship Canal which, when opened in 1900, permanently reversed the flow of the Chicago River from Lake Michigan (Mayer and Wade, 1969).

Growing urban ills associated with rapid urbanization and a new romantic view toward nature kindled the progressive movement. The City Beautiful and Garden City movements, and later greenspace advocacy, sought to mitigate unhealthy conditions in the cities through the preservation and restoration of vegetation and open space. Notably in the Chicago metropolitan region, efforts in this direction have led to the creation and preservation of extensive forest preserves, parks, and an open lakefront.

The Plan of Chicago, a classic example of the formalistic City Beautiful Movement, was published in 1909 by the Commercial Club of Chicago (Fig. 12). It directed regional growth and became a guideline for official city policy. The plan, coauthored by Daniel Burnham, was inspired in 1893 by the World's Columbian Exposition, which was held in Chicago and presented carefully designed public grounds and buildings in Jackson Park (Burnham and Bennett, 1909).

The tasks identified in the Plan of Chicago were to study the city's physical condition and how it could be improved, and to provide a guide for future development. It called for a continuous greenbelt of forest preserves, parks, and boulevards around the city, extension of lakefront parks and beaches through landfill, and development of encircling rail and highway

Figure 12. System of streets, boulevards, parkways, and parks from Plan of Chicago (Photo courtesy of Chicago Historical Society).

mass transit (Burnham and Bennett, 1909). Grant Park, Cook County's forest preserves, Chicago's unique open lakefront, and the elevated train system are all manifestations of the plan (Mayer and Wade, 1969).

The naturalistic works of Jens Jensen, typical of the Garden City style, also had a significant influence on the development of Chicago's greenspace. In addition to his park and residential designs, Jensen and other members of the Friends of Our Native Landscape focused effort on preserving native landscape types. The Friends published Jensen's "A Park and Forest Policy for Illinois" from which the Illinois State Park system evolved (Doty, 1991).

Together with Dwight Perkins, Jensen influenced the development of neighborhood parks and the Cook County forest preserves. Both were active in the Municipal Arts League, Prairie Club, Cliff Dwellers, and the Geographic Society of Chicago, all of which were concerned with open space and vegetation in the region (Netsch, 1989).

Also noteworthy are Chicago's many playgrounds. One of the first playgrounds in America was organized by Jane Addams' Hull House in 1894 in Chicago (McArthur, 1989). Further development came from the Commercial Club and the Chicago Playground Association, which acquired vacant lots for city playgrounds.

More recent efforts have focused on open-space advocacy undertaken by not-for-profit organizations such as the Open Lands Project. Founded in 1963, Open Lands is dedicated to preserving open space for recreation and conservation, and educates the public on the benefits of open space (Open Lands Project, 1982-83). Projects have included the Illinois Prairie Path begun in DuPage County, other coordinated trails, paths and open spaces throughout the region, urban forestry programs, and wetlands research. Other groups currently concerned with landscape preservation include The Nature Conservancy and the Illinois Nature Preserves Commission (Christy, 1986).

Municipal Forestry

Before the Chicago Fire of 1871, streets in the city were so well planted as to suggest Chicago's motto, "Urbs in Horto" or "City in a Garden." Most of the city's trees were destroyed by the fire, and in the push to rebuild, trees were not of great civic concern until 1904. A "Tree Planting Society" was then organized to promote the planting and care of street trees. In 1909, the Chicago Women's Club sought creation of a Chicago Tree Committee made up of representatives from many civic groups (Prost, 1911).

Mayor Busse responded to these concerns by drafting an ordinance that assigned control of street trees to the Special Park Commission. The ordinance also created the position of City Forester to oversee the preservation, culture, and planting of shade trees. It delegated responsibility for the care of street trees to adjacent property owners and provided for a permitting process and protection of street trees.

The earliest program had all of the components of today's successful municipal urban forestry program. Because the program was not initially funded except

for the city forester position, it focused on encouraging and coordinating the efforts of many local community groups. With its first appropriation of $3,000, the program undertook tree trimming and removal of hazardous dead trees. Arbor Day in 1911 was celebrated with the planting of 300,000 seedlings by school children.

The first City Forester in Chicago, J. H. Prost, described the significance of his work: "Trees planted in front of every home in the city cost but a mere trifle, and the benefits derived therefrom are inestimable...and every city could well afford to make this its first endeavor toward a 'City Beautiful'" (Prost, 1911, p. 277).

Parks

Beginning with 2 acres (.8 hectares) ceded by the U.S. Army in 1839, Chicago's parks gained international renown by 1915. The first haphazard parks were followed by a system of large regional and later neighborhood parks. An extensive inventory and evaluation of Chicago's parks has been accomplished (Vinci et al., n.d.) and preservation and restoration activities are underway.

Chicago's parks are a response to many of the issues defined by the early reformers. The impetus for the creation of the large landscape parks was concern for public health, recreation, and property values. These regional parks were designed to provide passive recreation and contact with a pastoral nature. The parks and boulevards were a key feature of Burnham's Plan of Chicago. Those placed in then open prairie strongly attracted and directed the city's growth (Fellmann, 1957).

The result of efforts by Frederick Law Olmsted, Calvert Vaux, Jens Jensen, and others was a continuous greenbelt around the city created by Lincoln and Humboldt Parks to the north, Garfield and Douglas Parks to the west, and Washington and Jackson Parks to the south. The six parks were connected by an innovative system of landscaped boulevards, designed as pleasure drives. These included the Midway Plaisance from Jackson to Washington Parks and Drexel Boulevard continuing north (Fig. 13). For the World's Columbian Exposition in 1893, Frederick Law Olmsted designed a unique system of lagoons in Jackson Park that partially exist today.

These large parks, typical of the romantic style of the classic English landscape tradition, featured expanses of lawn and groupings of trees. On the west side parks, Jensen used native plant species and began to define the informal prairie style of landscape architecture.

The era of the large landscape parks ended around 1900 and was followed by the development of small neighborhood parks. These parks provided facilities for outdoor and indoor recreation of which the fieldhouse was a common feature. Representative of this park type are Hamilton, Dvorak, and Avalon Parks (Vinci et al., n.d.).

Several park districts that at the time were outside of Chicago were merged in 1934 with Chicago's Lincoln, South, and West Park Commissions into the Chicago Park District, an autonomous body that manages the city's parks. Most suburban communities have their own park system.

Figure 13. Drexel Boulevard in 1891 (Photo courtesy of Chicago Historical Society).

There are now more than 7,332 acres (2,967 hectares) of park (Mun. Ref. Library, 1991). and 450 acres (182 hectares) of boulevards (Bylina, 1991) in the City of Chicago. Nearly all of the larger landscape and smaller neighborhood parks have been altered through time and are now closely identified with their neighborhoods.

Forest Preserves

Dwight Perkins' and Jens Jensen's call for a continuous belt of regional parks and forested areas around the city was echoed by Daniel Burnham in the Plan of Chicago. Two years after passage of a legislative act in 1913 enabling the creation of forest preserves in Illinois, the Cook County Forest Preserve District was organized (Morrill, 1970). The district has authority to acquire and hold lands containing forests, or those connecting such forests, for public education and recreation.

The first purchase made was a 40-acre (16-hectare) tract in Palatine

Township (Bishop and Gilbert, 1933). Other initial efforts to save native woodlands were focused along the North Branch Chicago and Des Plaines Rivers (Chicago Recreation Comm. and Northwestern Univ., 1937). These tracts of land, along with those preserved natural areas of indigenous vegetation and wildlife, generally are in the suburbs but do enter the city along the North Branch Chicago and Des Plaines Rivers and part of the city's south side.

Initially, no more than 35,000 acres (14,164 hectares) could be acquired by the Cook County Forest Preserve District. By 1929, the maximum had nearly been reached. Since then, the limit has been lifted and holdings now exceed 67,000 acres (27,115 hectares) (M. Costello, Cook County For. Preserve Dist., pers. comm., Feb. 27, 1992).

The various preserves are maintained in a wild condition except for areas of intensive recreational use, including golf courses, picnic areas, fishing ponds, and swimming pools. Linking wild forested and recreation zones is a system of bicycle and pedestrian trails. Although enabling legislation directed the district to preserve and restore native landscapes, most management since 1929 has promoted forestation and fire prevention (Christy, 1986). Some of the more recently obtained land has been in agricultural use and allowed to slowly revert to forest over time. However, the Forest Preserve Districts of Cook and DuPage Counties and other conservation groups have initiated a number of projects to restore and preserve both prairie and forest.

The system of DuPage County forest preserves was well established by 1925 with 800 acres (323 hectares) (Morrill, 1970). The DuPage County Forest Preserve District, similar to the Cook County district, has acquired land for preservation, recreation, and education. The first land purchases began in the southeast corner of the county, near the Argonne National Laboratory. Currently, more than 22,000 acres (8903 hectares) in DuPage County are in forest preserves (Johnson, H.C., For. Preserve Dist. of DuPage County, pers. comm., April 1, 1992)

Other important municipal organizations that manage open space include the Metropolitan Water Reclamation District, which owns 7,000 acres (2,833 hectares) along Chicago's waterways, the Chicago Board of Education, which has 582 playgrounds on 350 acres (142 hectares), and the City of Chicago has an increasing inventory of vacant land parcels (Christy, 1986).

PRIVATE LANDS

A significant portion of Chicago's urban greenspace is privately owned. Private control of lands ranges from institutions and corporate campuses to single- and multiple-family residences.

Institutional

Some large parcels of greenspace in Chicago are privately owned by religious, recreational, and research institutions. Examples are arboretums, golf courses, and cemeteries.

Chicago's cemeteries have a particularly interesting history. One of the first cemeteries was located downtown and had to be moved because of the city's growth. The cemetery relocated for Lincoln Park already had been moved once. Remains were moved to their final resting place in Graceland and Rosehill Cemeteries. Both of these large cemeteries were designed in the naturalistic style, with beautiful lawns, trees, and water features. Other historically significant cemeteries are Oakwoods, Forest Home, Waldheim, Calvary, and Mount Greenwood, which combined with Graceland and Rosehill covered nearly 1,000 acres (405 hectares) in 1891 (Schick, 1891).

In 1922, Joy Morton, son of the founder of the first Arbor Day, J. Sterling Morton, established the Morton Arboretum on 400 acres (162 hectares) in DuPage County as an outdoor museum for the study of woody plants (Bishop and Gilbert, 1933). The arboretum now covers more than 1,500 acres (607 hectares). The institution is privately endowed to conduct research on cultural requirements and new introductions of plant species for Illinois. Important research findings are shared with the community through educational programs.

Other institutions that maintain greenspace include research facilities, local universities, and hospitals. During the period of urban renewal in Chicago, Michael Reese Hospital and the campuses of the Illinois Institute of Technology and the University of Chicago extended their acreage over blighted residential areas on the city's south side (Mayer and Wade, 1969).

Control of agricultural lands ranges from institutions like Fermi National Accelerator Laboratory to small family and individual ownerships. Expansion of industries and municipalities into rural areas has been at the expense of agricultural land, which continues to be developed (Cutler, 1976). Most private open land in the Chicago metropolitan area was previously in crop production (Miller, 1962).

Residential

Residential land uses cover the largest area in the metropolitan region (Iverson, 1988), so the vegetation around homes is a significant portion of urban greenspace. A comprehensive study of residential landscapes in the Chicago region was conducted by Schmid (1975). Within the city, single-family housing typically contains one or two trees, foundation shrubs, and the ubiquitous lawn. Platting based on the General Land Survey has produced a rigid rectilinear lot layout which contrasts with the more curvilinear form of recent tract developments in the suburbs.

Landscape tastes have affected species composition in both urban and suburban areas and led to increasing floristic homogeneity. Exotics have been favored, beginning with the arrival of the now condemned tree of heaven (*Ailanthus altissima*) brought by early settlers. Suburban development occurs on abandoned agricultural lands along with a small but increasing effort to reestablish native landscapes. However, natives are preserved on wooded tracts, which generally sustain higher land values.

Closed landscapes, which are dominated by vegetation, were first popular among residences along the lakeshore north of Chicago, and still exist in wealthier suburbs (Fig. 14). They generally are created from indigenous presettlement vegetation assemblages and often are not planted consciously. Separation of private and public space is sharply defined by the visual barriers provided by masses of vegetation.

Open landscapes, derived from the romantic landscape tradition in which architecture overshadows vegetation, predominate more now than in the past (Fig. 15). Trees and shrubs are not allowed to attain the size or density necessary to create a visually closed landscape. Privacy in open landscapes is absent or achieved by large lot size and distant setback.

A significant change on municipal and residential landscapes began with the introduction and spread of Dutch elm disease (DED). Prior to the 1960's, *Ulmus americana* was the preferred street tree. Heavy losses of street and yard trees to DED have encouraged efforts toward sanitation and increasing species diversity to reduce the opportunity of monocultural epidemics.

Of increasing concern in residential areas of the city is the growing number of vacant properties. Generally a liability, these can become a resource in an urban open space system. Where community interest and organization is strong, vacant lots are sometimes used as community gardens (Christy, 1986).

Figure 14. A Glencoe house enclosed by native forest (From Schmid, 1975).

Figure 15. Open landscape developed from agricultural land in Park Forest (From Schmid, 1975).

4 URBAN FOREST MANAGEMENT

Urban forests in the Chicago area fall under the jurisdiction of many agencies and institutions. Parks are the responsibility of park districts, independent taxing bodies governed by a board of commissioners. Trees along city streets are the domain of municipal forestry programs. The Illinois Department of Transportation and county governments maintain trees along highways and larger arterial streets. Other agencies, such as school districts and sanitary districts, also play a role in the management of public greenspace. The Cook and DuPage County Forest Preserve Districts manage large forested and natural areas primarily for recreational purposes.

The following section reviews the roles of greenspace managers within the CUFCP study area. Management by different governmental entities in Chicago and suburban communities is described. The important role of private firms in the landscape industry is examined. General observations are presented regarding urban forest policy, funding, education, and advocacy. The section concludes with a synopsis of current and future challenges.

URBAN FORESTRY IN THE CITY OF CHICAGO

Today, three organizations are primarily responsible for planning and managing Chicago's street and park trees. The recent histories and management roles of the Bureau of Forestry, GreenStreets, and the Park District are discussed.

Bureau of Forestry

The Bureau of Forestry, part of the Chicago Department of Streets and Sanitation, employs about 306 people and maintains about 450,000 street trees and 450 acres (182 hectares) of boulevard trees and lawns (Bylina, 1991). It also maintains its own nursery and facility for processing wood waste. The bureau handles nearly all tree work itself, resorting to contractual work only during a crisis or to eliminate a serious backlog. Its annual budget is approximately $13 million, with funding from the Corporate Fund in the city budget.

The bureau's recent history was shaped by the DED epidemic which hit hard in the late 1960's, leaving hundreds of thousands of dead trees in its wake. Chicago, like many other communities, was unprepared to handle the outbreak; in 1971, there were 100,000 dead trees on the parkways (Krohe, 1990). Tree trimming was abandoned except in emergencies as the removal of dead and diseased trees had the highest priority (Swanson, 1981). Tree removal rates were the highest ever in 1969-71; between 25,000 and 50,000 trees per year and planting rates kept pace (Swanson, 1981; Siewers, 1987). As the crisis was winding down, the Chicago Department of Planning

prepared a report to guide the public in reforesting the city (Chicago Dep. of Plann., 1974).

In 1980, the Bureau of Forestry's budget was cut severely, from $12.8 million to $8 million (Krohe, 1990), and 200 of its 525 employees were laid off (Mabley, 1979). The years that followed left the forestry unit without clearly defined priorities. Trees were removed upon request regardless of condition and tree trimming was done on a limited basis. Planting didn't keep pace with removals as only one of ever three trees removed was replaced. Between 1980 and 1988, Chicago lost 128,000 trees even though DED no longer posed a significant threat; the American elm population was sparse and scattered (Green, 1985). For a short period, the Bureau of Forestry became a division in the Bureau of Streets.

After he took office in 1989, Mayor Daley increased the Bureau of Forestry's budget by 25 percent and encouraged professionalization of the work force. By 1991, more than 100 tree trimmers were certified as arborists by the Illinois Arborist Association (Bylina, 1991). The Bureau has reestablished trimming as a priority, setting a 6-year pruning cycle as a goal. The mayor initiated a policy that prohibits the removal of live and sound trees and doubled the number of trees planted to 10,000 a year.

GreenStreets

In 1987, the Open Lands Project created a program to draw attention to the plight of Chicago's trees. Called NeighborWoods, the group enlisted community groups to plant and care for trees on public property and lobbied for improved care of public trees. By 1989, NeighborWoods visibility and a growing urban forest constituency attracted the attention of Mayor Richard M. Daley.

The mayor developed a comprehensive program for greening the city and hired the Director of NeighborWoods to implement it. Called GreenStreets, the program was placed in the Mayor's Office so that the efforts of many city departments could be coordinated. GreenStreets' goal was to add 500,000 trees through preservation, planting, and maintenance. Mayor Daley's personal fondness for trees inspired an unusually high degree of cooperation among the many agencies, business, and civic groups. This could bring about a significant change in Chicago's urban forest because strong community involvement is an important feature of the program.

GreenStreets pursued corporate and foundation funding. In 1989, the mayor created the Urbs in Horto Fund, in cooperation with the Chicago Community Trust, to make grants to community groups that wished to plant and maintain trees in their neighborhoods. That same year, Chicago also received USDA Forest Service funding for preliminary work on the CUFCP.

Among the greatest accomplishments of GreenStreets was the unanimous passage in 1991 of a landscape ordinance that calls for the mandatory planting of parkway trees following construction or major rehabilitation of any building larger than a residential three flat. It also requires the planting and maintenance of screening and interior landscaping, including trees, for any parking lot visible from

a public right-of-way. The Department of Zoning may withhold a Certificate of Occupancy, required for the operation or use of a commercial building, until the Bureau of Forestry approves the site for compliance with the landscape ordinance (City of Chicago, 1991).

The Chicago Park District

The Chicago Park District addresses tree planting and care primarily through its Horticultural Services Department. The department is responsible for the construction and rehabilitation of all new athletic fields, soft-surface playlots, and landscape improvements, and for maintaining 560 parks ranging in landscape complexity from a neighborhood playlot with a few trees, to Grant Park which is home to the largest stand of American elms in the Midwest, a rose garden, Buckingham fountain, and acres of flower beds.

The Park District, like the Bureau of Forestry, performs most of its work in-house. It employs about 260 people in Horticultural Services and another 16 landscape architects in Landscape Design (Urso, E., Chicago Park District, pers. comm., Feb. 21, 1992). In 1991 the Park District appropriated $8 million for greenspace design and management, including mowing, litter pick-up, tree and flower bed maintenance, and nursery and greenhouse operations.

During the prolonged drought of 1988, the Park District developed an innovative method of watering trees that attracted considerable attention and volunteers help. The Water Wheel, or Hydro-Kielbasa, is a length of thin plastic tubing that when filled with water creates a reservoir around the base of the tree, allowing a long, slow soak.

Of particular interest in Chicago is the grove of American elms in Grant Park, one of the largest remaining stands of elm in the Western Hemisphere. This magnificent stand of 1,100 trees has resisted the onslaught of DED, though several are lost to the disease each year (Recktenwald, 1990).

The Park District works closely with advocacy groups such as Friends of the Park, a watchdog organization for Chicago's parks. This group was instrumental in both the issuance of and efforts to comply with a federal consent decree that sought to equalize the distribution of park resources throughout the city. Friends of the Park also works with citizen-based Park Advisory Councils that represent each park. A number of unique landscape projects has been undertaken by these councils, such as a prairie restoration project in Indian Boundary Park.

As part of a comprehensive plan for Lincoln Park, Chicago's largest and most heavily used park, a detailed survey and analysis of all 10,000 trees was completed in 1990. This inventory helped heighten awareness of the value of the tree resource and identified specific tree-care needs. For example, it was noted that trees have been damaged extensively by picnickers who dump hot coals at the base of a tree after grilling. The Park District is launching a public education campaign called Save the Shade to prevent such damage in the future.

URBAN FORESTRY IN THE SUBURBS

Municipal forestry programs in suburban Chicago run the gamut in management approaches and levels of sophistication. For example, many suburbs use tree-care contractors to provide some or all needed services, while others employ fulltime city foresters. The oldest urban forestry programs are in the northern suburbs of Cook County and the established suburbs of DuPage County. Rapidly developing suburbs such as Naperville in western DuPage County experienced a building boom in the late 1970's and early 1980's, but did not hire urban foresters until the mid-1980's.

Older suburban communities such as Evanston, Oak Park, and Park Ridge have well-funded, aggressive, state-of-the art urban forestry programs. Park Ridge spends $10.55 per capita on trees, among the highest in the state, and offers a comprehensive program including Dutch elm disease (DED) control and brush and leaf pick-up. It has developed specifications that require utilities to protect the roots of parkway trees by augering beneath them rather than trenching. Oak Park has a complete computerized inventory, an extensive master plan, and a successful community outreach program. Evanston has offered a unique municipal insurance program for owners of American elms on private property, assuring prompt removal of diseased trees. Because of early efforts at DED control, large numbers of American elm trees in these towns have been protected from the blight.

Other communities, such as the older industrial suburbs that ring the city and many of the south suburbs, have not yet implemented comprehensive programs to manage trees on the public right-of-way. Inadequate funding is the most limiting factor to program development (Illinois Counc. on For. Dev., 1988).

Some suburbs are beginning to pool their resources to better manage their trees. The West Suburban Municipal Conference has developed a tree-purchasing consortium with a nearby nursery to contractually grow trees for a set number of years. The consortium keeps costs down and assures a steady supply of high-quality stock for municipalities, as well as guaranteed sales for the nursery.

The issue of pesticide application has been an important urban forestry issue in many suburbs. Lawn-care firms are much more active in the suburbs than they are in the city, and residents are increasingly demanding tighter regulation of pesticide use on both public and private landscapes.

Conflicts between trees and utility lines are a concern, especially in older suburbs where large trees growing into power lines is common. In Chicago, utility lines run down alleys instead of parkways where the trees are, and in newer suburbs lines usually are installed underground to avoid conflicts. Commonwealth Edison contracts for line clearance tree trimming throughout the study area. The utility is developing remove-and-replace programs with many communities, and works to discourage the planting of tall-growing trees under wires.

URBAN FORESTRY IN THE PRIVATE SECTOR

The landscape industry is a key player in shaping urban forest trends in the Chicago area. Its presence on private property does much to educate its client, the public, and create expectations of public programs.

Residents in communities with strong municipal programs often have high standards for tree care and are more likely to invest in the maintenance of their own greenery. According to a survey of the green industry, residential tree care makes up 68 percent of the total work; commercial work accounts for 13 percent and municipal contracts for 7 percent of all tree care revenues (Illinois Counc. on For. Dev., 1988).

After the repeal of the Illinois Tree Experts license in the mid-1970's, the tree-care industry spearheaded a move to regulate itself. The Illinois Arborist Association has administered this program and many certified arborists practice in Illinois. Most recently, the International Society of Arboriculture has began to standardize arborist certification programs across the country, including Illinois.

URBAN FOREST POLICY

Public pressure has shaped urban forest policy in Chicago, and other areas. Residents in both the city and its suburbs have historically responded to poor management of the natural environment whether as dramatic as the poor, dirty living conditions that led to the progressive reform era, or the infamous felling of trees by Mr. T in Lake Forest that led to a regulation on the removal of trees on private property. The public has demanded and in most cases received sound urban forest policies.

Dutch elm disease, which swept through the Chicago area in the 1960's and early 1070's gave rise to the majority of community forestry programs. Development pressures, particularly in the outlying suburbs, has brought about many urban forest policies that address both planting around new residential and commercial areas, and tree preservation in wooded areas. DuPage County enforces a landscape ordinance that not only requires planting for screening but also provides rewards for the preservation of existing plant material. The ordinance targets transition yards, or yards between two land use types, and parking lots.

Tree City USA also was an important catalyst for the initiation of urban forestry in the Chicago area. Since its establishment in 1976, dozens of communities around the state have begun to manage tree resources more carefully. They have been assisted by the Illinois Department of Conservation, which administers this program. Currently, there are 24 Tree City USAs in Cook and DuPage Counties and another 62 in the rest of the state. The resurgence of environmental awareness surrounding the 20th anniversary of Earth Day in 1990 has led to many strong civic, corporate, and institutional tree campaigns.

FUNDING FOR URBAN FORESTRY

In the early 1980's, the Illinois Council on Forestry Development recognized that many cities could not afford to address urban forest management. This group recommended to the General Assembly the Urban Forest Assistance Act, which would authorize the Department of Conservation to issue matching grants to municipalities to aid their tree programs. This legislation was enacted in 1984 but was not funded, (Illinois Comm. on For. Dev., 1986).

Communities throughout Illinois now have access to matching federal funding for urban forestry. President Bush created America the Beautiful (ATB) to, among other things, assist communities in better managing their tree resources. The Illinois Department of Conservation, which administers these federal programs, anticipates the first round of ATB grants to communities to be available in the summer of 1992. Another federal program of the Small Business Association has in 1991, its first year, provided more than $600,000 in aid to Illinois communities exclusively for the purpose of contracting with small firms to plant trees on public lands.

PUBLIC EDUCATION AND ADVOCACY

Public education about the urban forest provides critical support for policymakers at all levels. Several local institutions have taken the lead in this area, including the Morton Arboretum, Chicago Botanic Garden, University of Illinois Cooperative Extension, as well as numerous nature centers and associations.

The Arboretum and Botanic Garden offer classes, programs, library resources, and, of course, landscaped grounds and educate their members and the general public about plants. The Extension Service concentrates its efforts on educating landscape professionals. Nature centers, managed privately or by the county or cities, expose students to natural areas, wildlife, and ecological concepts. The Open Lands Project recently has developed a program called Tree Keepers to train community leaders in basic tree care.

Also vital to the environmental education movement are local neighborhood groups, improvement associations, and garden clubs. These groups usually can command the attention of local elected officials about tree concerns. For example, a Girl Scout troop brought so much media attention to a large oak on property slated for development in Bolingbrook that plans for a shopping center were altered to save the tree (Chicago Trib., 1991).

These advocacy groups have brought about significant change, especially in Chicago where neighborhood identity is strong. Thirty civic groups were originally involved in urban forestry in the 1900s and comprised the Chicago Tree Committee. Civic involvement has grown steadily to include at least 70 groups that participated in Open Land's community greening projects in the late 1980's (Prost, 1911; Krohe, 1990).

There is a growing trend toward linking open space in the region for recreational purposes, though this movement has stirred some controversy. A coalition of environmental groups and regional and local units of government is proposing a

Regional Greenway that will link and expand existing open space. Existing trails in the region are popular for biking and hiking, but often are crowded. Property owners adjacent to proposed trails are sometimes vocal in their opposition. A group called STOP, Stop Taking Our Property, lobbied Governor Edgar to stop the Kane County Forest Preserve District from completing a section of bike trail along the Fox River.

CURRENT AND FUTURE CHALLENGES

The challenges facing Chicago and suburban communities differ in scope and urgency. Because Chicago and its nearest urban suburbs such as Evanston, Oak Park, Cicero, and Berwyn are largely built-out, there are few opportunities to create new greenspace. An exception is reclaiming a previously developed area. Thus, the focus of Chicago's recent tree program is to plant existing greenspace, provide regular tree care, and create new greenspace by retrofitting trees into paved areas. Mayor Daley's GreenStreets program has attempted to replace trees on nearly completely paved school grounds by literally cutting concrete to create spaces to plant. Highway right-of-ways, though not paved, have been underutilized as greenspace and now are being designed and planted by an energetic new civic group know as Gateway Green. The downtown area and other commercial areas pose particularly tough challenges for tree planting because of limited access to soil.

Many older, less dense suburbs such as Park Ridge, Niles, La Grange, and Hinsdale were developed with adequate parkways, public areas, and parks. These communities have extensive, healthy tree populations and do not have the expanses of concrete that so compels Chicago to plant. Their challenge lies in maintaining the health and increasing the diversity of an older urban forest.

Rapidly developing suburbs on the outskirts of Cook and DuPage Counties face a different challenge. Communities like Carol Stream, Schaumburg, and Naperville developed rapidly on old farm land that had little initial tree cover. Today, their concerns center mainly on requiring developers to include landscaping in their projects. Large numbers of strip malls were developed that are devoid of landscaping, and some large residential developments look essentially barren because all of the landscaping is new.

Other suburbs on the edge of the wave of regional development, such as Barrington and St. Charles, still have the opportunity to preserve trees during development and are enacting ordinances to do so. The McDonald's restaurant chain's corporate campus in Oak Brook was developed with great sensitivity to the existing landscape. It is considered a national model for wise development on wooded sites.

5 URBAN FOREST COVER

Urban forest cover varies across a region due to differences in amount of growing space, social preferences and policies, age of development, land use, and growing conditions. Tree cover (as a percentage of total land cover) generally increases along the urban-rural gradient: a theoretical transect extending from the city center to exurban areas. This trend is largely due to lower amounts of available growing space and less suitable growing conditions in highly urbanized settings.

Information about the amount and distribution of tree cover can be used to gauge the amount of influence trees have on the environment (Nowak, 1991). The higher the cover, the more trees influence the surrounding environment. Urban forest cover data also indicate the potential for new tree plantings by including analyses of the amount of area occupied by other urban surfaces that impede or facilitate planting (i.e., buildings, pavement, water, grass, and soils). Analyses can also reveal relations between existing tree cover and planting potential among different land use types (e.g., residential, commercial, institutional).

To better understand the distribution of urban vegetation throughout the CUFCP study area a tree cover analysis was conducted using aerial photographs. The following sections describe the methods and findings of this research. Urban forest cover data will be supplemented by field data collected during the summer of 1992. Together, these data will provide one of the most detailed pictures of an urban forest structure ever compiled.

COVER ANALYSIS OF THE CHICAGO REGION

To analyze cover types the Chicago region was divided into three sectors: 1) Chicago, 2) Cook County (exclusive of Chicago), and 3) DuPage County. (References to Cook County within the remainder of this section refer to the area outside of Chicago.) Each of these three sectors were further subdivided into community areas for more refined analysis (Fig. 16). Community areas in Chicago are planning zones with each comprising several census tracts. In Cook and DuPage Counties, community areas are delimited by township ranges.

Within each community area, cover types were analyzed by randomly locating a minimum of 300 dots on aerial photographs (1987; 1:4800) and classifying each dot as to land use type and cover type (Table 2). Cover proportions are calculated by dividing the number of dots in the category of cover type by the total number of dots in that community area. For example, total number of dots classified as trees (e.g., 10) is divided by the total number of community area dots (e.g., 100) to estimate tree cover (10/100 = 10%).

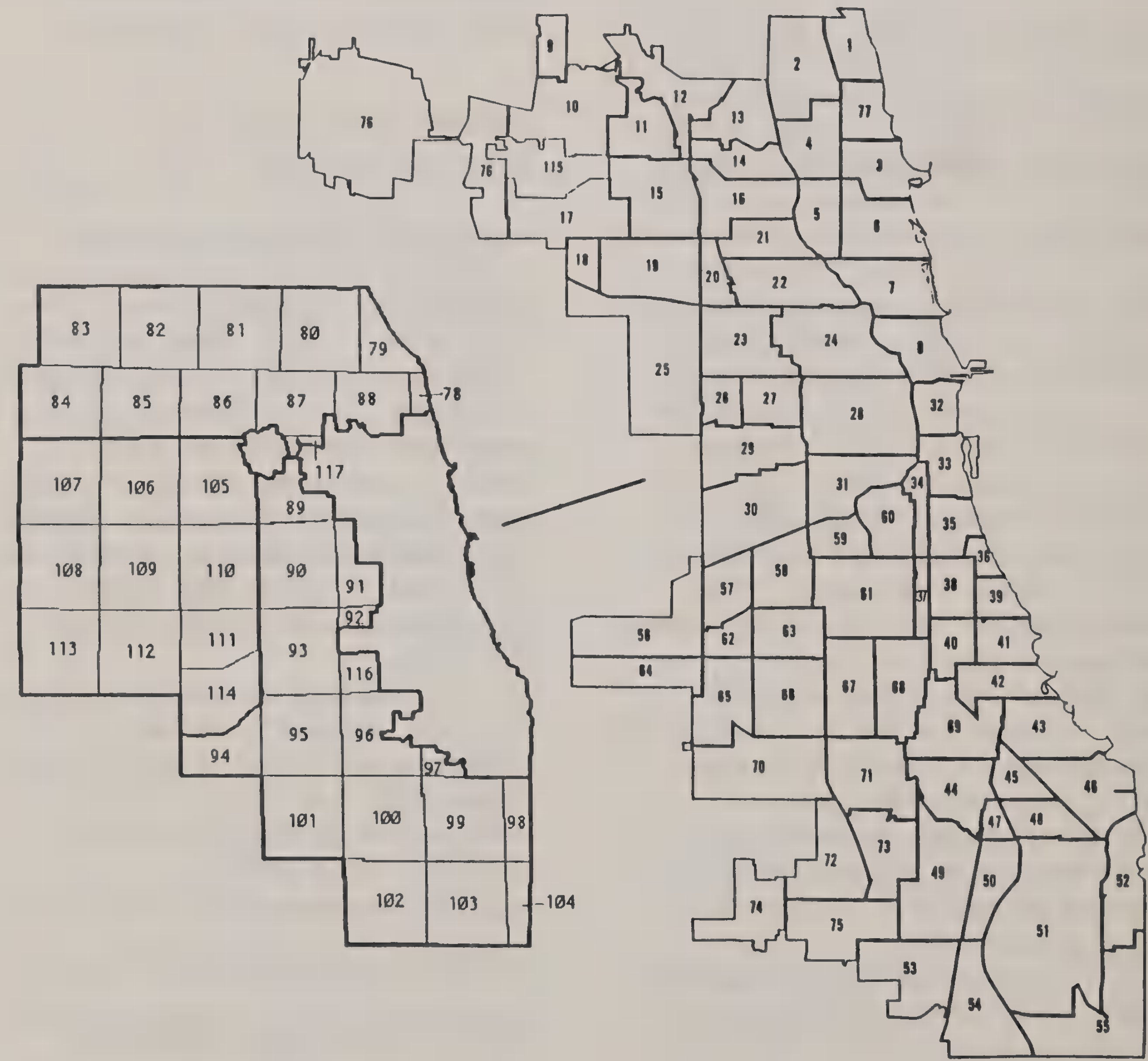

Figure 16. CUFCP community areas in all sectors.

Table 2
Land Use and Cover Type Categories

Analysis	Type	Category
Land Use		
	Residential	1 to 3 family (per structure)
		≥ 4 family (per structure)
	Commercial/Industrial	small sq. ft. (e.g., small shops)
		large sq. ft. (e.g., malls, warehouses)
		park-like complex
	Institutional	building dominant (e.g., education, hospital)
		park dominant (e.g., parks, golf)
		forest preserve
	Transportation	auto (limited access highways)
		other (e.g., railroads, airport)
	Agriculture (land in crop production or animal husbandry)	
	Vacant/Wild (apparently unmanaged and unused land)	
Cover		
	Tree/Shrub	street (between sidewalk and road; medians)
		managed (off-street areas appearing to be managed)
		unmanaged (off-street areas appearing to receive little or no maintenance)
	Groundcover/Soil	street (between sidewalk and road; medians)
		managed (off-street areas appearing to be managed)
		unmanaged (off-street areas appearing to receive little or no maintenance)
	Building (permanent and temporary structures)	
	Paving (streets, parking lots, sidewalks, etc.)	
	Water (lakes, rivers, ponds, pools, etc.)	

Because of a dearth of leaf-on aerial photography of the Chicago region, the aerial photographs analyzed were taken during a time when vegetation was leaf-off. To test whether the leaf-off photography made a difference in the interpretation of tree cover, a portion of the City with leaf-on photography (1987; 1:8400) was exactly reanalyzed and no statistical difference between the leaf-on and leaf-off photograph interpretation was found (Chi-square test). Also no statistical difference between interpreter classifications of land cover was found. However, tree cover values may slightly underestimate actual tree cover to the extent that new transplants and other small trees could not be observed on the aerial photographs. Differences between current and reported land cover are expected because of changes since the time of image acquisition in 1987 and sampling variability. The greatest discrepancies are anticipated for urbanizing areas in Cook and DuPage Counties and Chicago, where extensive tree plantings during the past few years are not included.

Cover type percentages are used to calculate percentages of available growing space (AGS) and canopy stocking level (CSL). AGS is the sum of tree/shrub and grass/soil cover. AGS reflects the proportion of land that is not covered with buildings, paving, and water, and thus readily available for tree planting. CSL is defined as the percentage of AGS covered by trees (i.e., the ratio of tree cover to AGS). CSL reflects the degree to which potential tree planting spaces have been filled (McPherson and Rowntree, 1989). Areas with low CSL indicate relatively high tree planting potential. CSL is only a indicator of planting potential because areas with low CSL may not be suitable for trees due to other incompatible uses (e.g., ball fields, putting greens, and grass/soil areas that receive vehicular use).

FINDINGS

Average tree cover for the entire study area is 19.4 percent, ranging from 11.1 percent in Chicago to 22.5 percent in Cook County (Table 3). Grass cover increases along the urban-rural gradient from Chicago (26.9 percent) to Cook County (44.7 percent) to DuPage County (56 percent). Impervious surface cover (i.e., buildings and paved surfaces) decreases along the urban-rural gradient. In Chicago impervious surfaces account for 60 percent of total land cover versus only 31 and 23 percent in Cook and DuPage Counties, respectively. Increasing available growing space (AGS) along the urban-rural gradient (from 38 to 67 to 75 percent) reflects the increasing importance of vegetated surfaces. Canopy stocking levels (CSL) vary less than AGS, ranging from 25 percent in DuPage County to 33.5 percent in Cook County. Thus, the ratio of grass to tree cover ranges from 2:1 to 3:1. Lower grass to tree ratios in Chicago and Cook County may be due to higher tree densities and/or more mature trees. Tree densities on recently developed tracts in DuPage and Cook Counties may be similar to those in older tracts, but CSL is lower now because the tree cover is not fully grown. Alternatively, lower CSL values may reflect a conscious decision to restrict tree cover. Reasons for restricting tree cover include aesthetic preferences,

Table 3
Percentage Land Cover, Available Growing Space, and Canopy Stocking Level by Sector

Sector	Area (sq mi)	Tree	Grass	Bldg	Paved	Water	AGS	CSL
Chicago	237	11.1	26.9	27.4	32.4	2.2	38.0	29.2
Cook	722	22.5	44.7	12.6	18.2	1.9	67.2	33.5
DuPage	333	18.6	56.0	9.4	13.9	2.1	74.6	24.9
Total Study Area	1,292	19.4	44.4	14.5	19.7	2.0	63.8	30.4

management costs, and the desire to reduce conflicts between trees and other landscape features and land uses.

Canopy Cover by Sectors and Community Areas

Tree cover in Chicago's community areas ranges from below 5 percent to nearly 40 percent (Fig. 17). Generally, tree cover is lowest in the most intensively developed downtown areas, and is greatest in the lower density residential areas such as Forest Glen, Beverly, Edison Park, North Park, and Hegewisch. Cover percentages for each community area are included in Appendix B.

Cover in Cook County community areas ranges from 5.1 to 10 percent in locations immediately north and south of Midway Airport, to 40.1 to 50 percent in Palos Township, where the Palos Forest Preserves are located (Fig. 18). Townships with tree cover in the 30.1 to 40 percent range include New Trier, Northfield, and Lemont.

DuPage County townships with greater than 20.1 percent tree cover include Downers Grove, Milton, and York (Fig. 18). Tree cover is lower in most northern and western DuPage townships, largely due to less rapid conversion of agricultural land to urban uses.

Canopy Cover by Land Uses

Land use is perhaps the single most important variable related to urban forest cover because different land uses have characteristic development patterns that influence tree planting and survival Rowntree, 1984). The relative magnitude of land use types differ across sectors (Figs. 19, 20, and 21). For example, in Chicago residential and commercial land uses account for nearly three fourths of all land, whereas they occupy about half of the land in Cook and DuPage Counties. Agricultural land is virtually non-existent in Chicago, but makes up 13 and 21 percent of total land cover in Cook and DuPage Counties, respectively. The proportion of vacant/wild land increases along the urban-rural gradient as well. Institutional land covers 22 percent of Cook County, a large amount compared to values of 13 and 14 percent in the other sectors. Most of this difference is due to

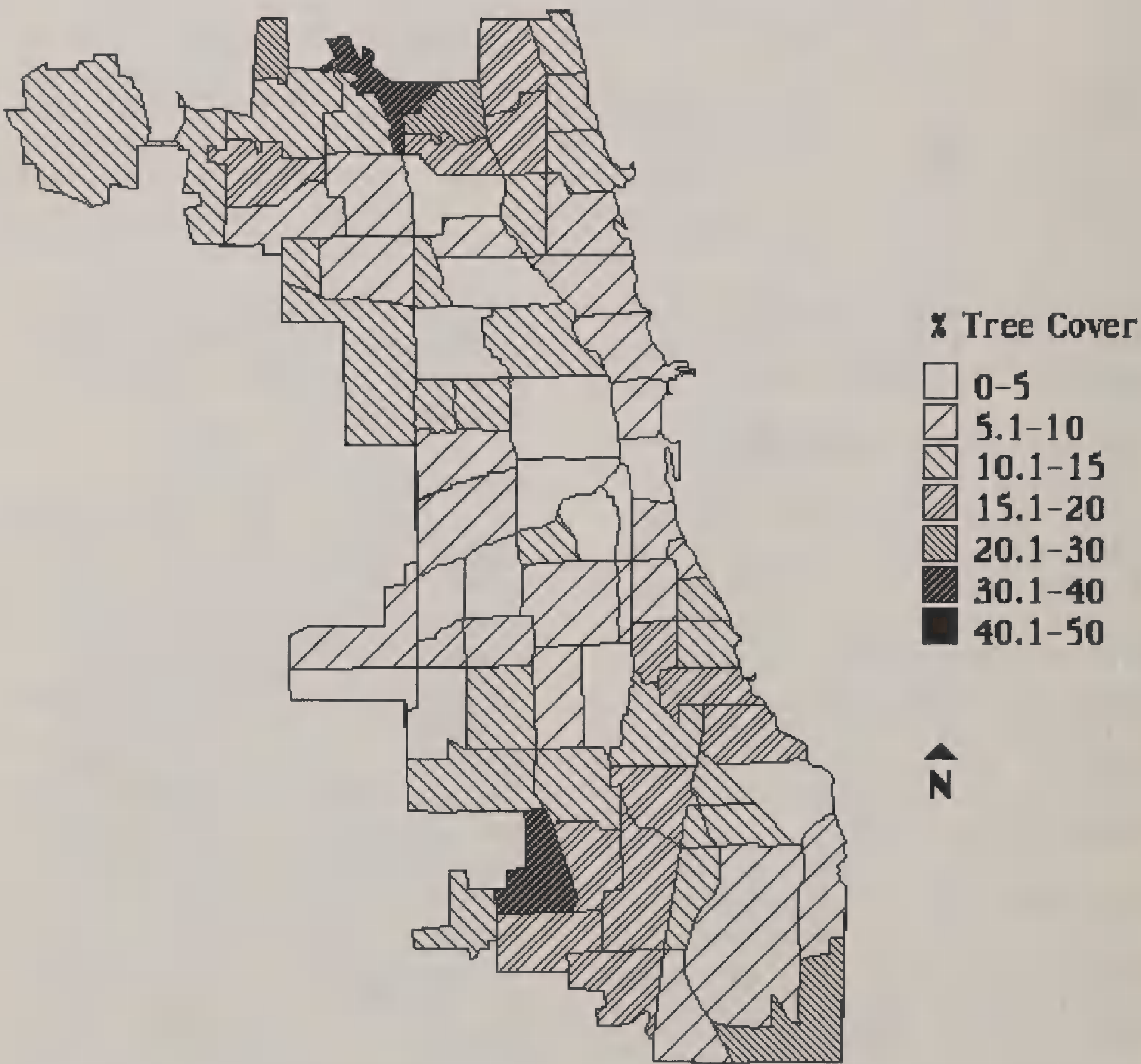

Figure 17. Tree cover by community area in Chicago.

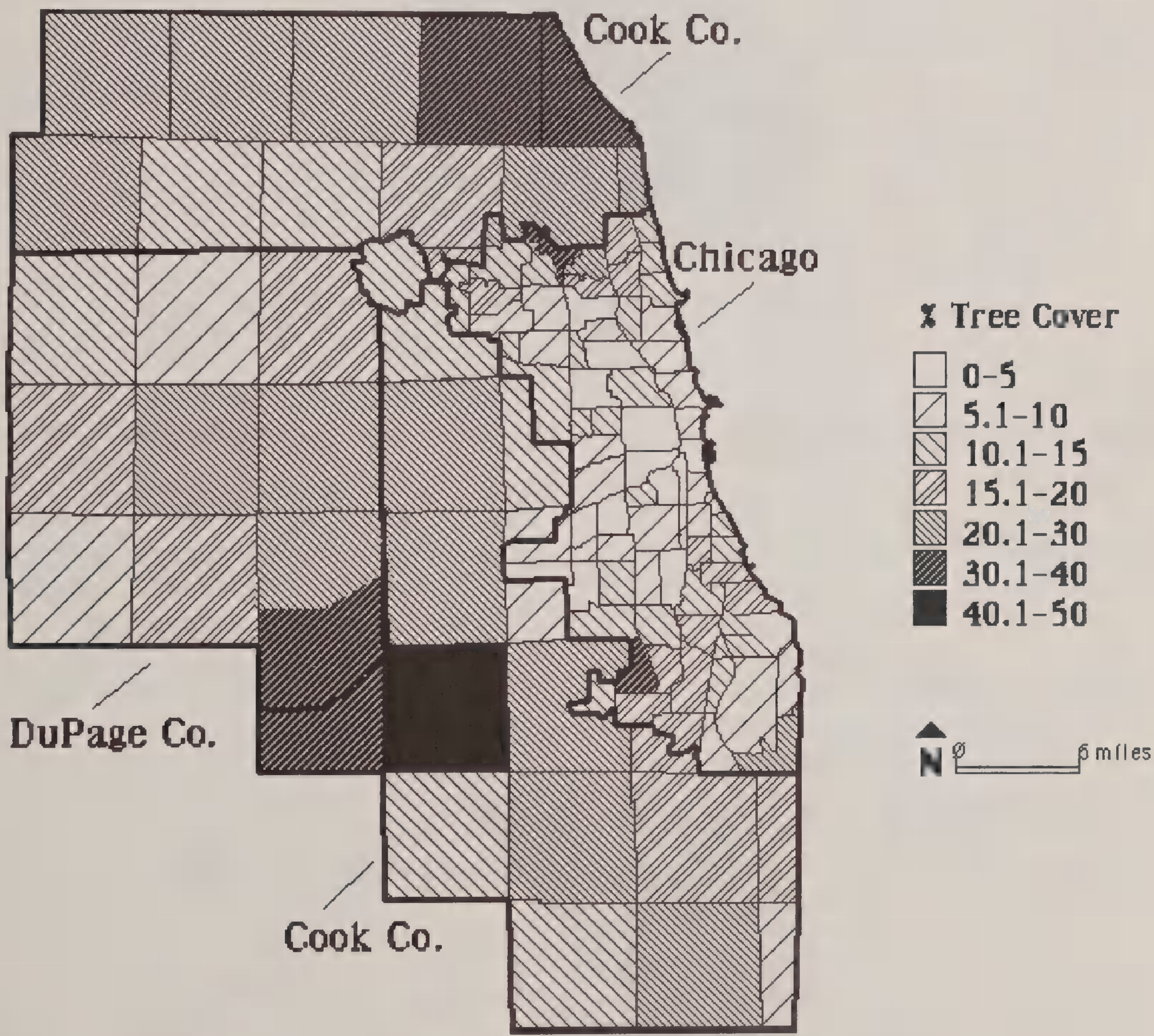

Figure 18. Tree cover by community area for all sectors.

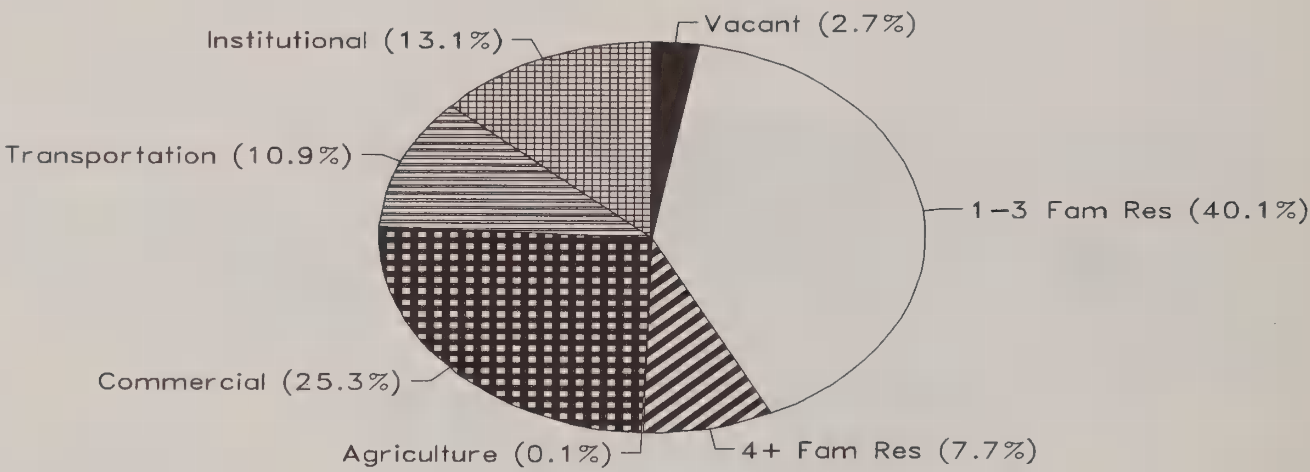

Figure 19. Land use in Chicago.

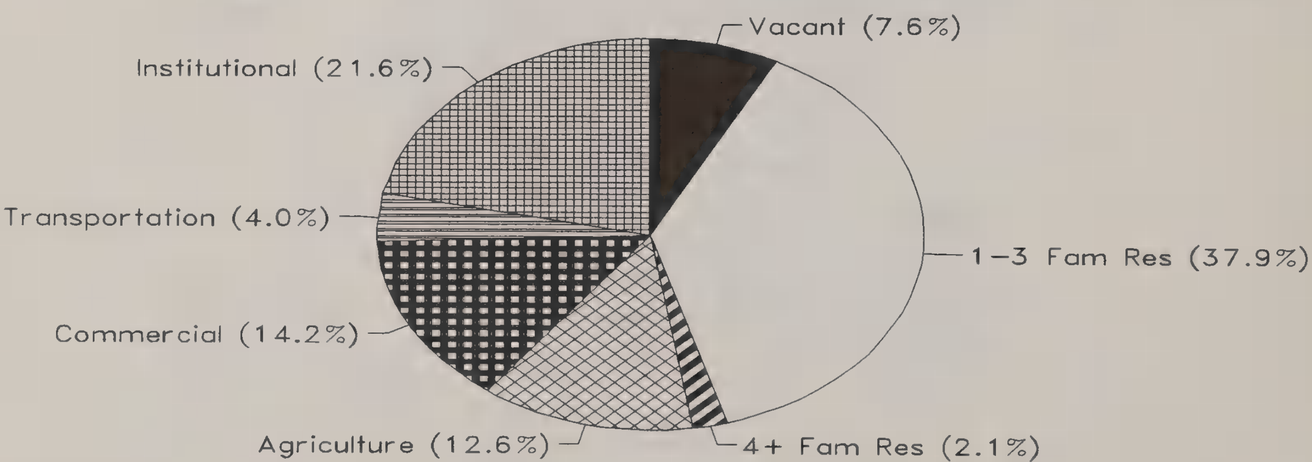

Figure 20. Land use in Cook County.

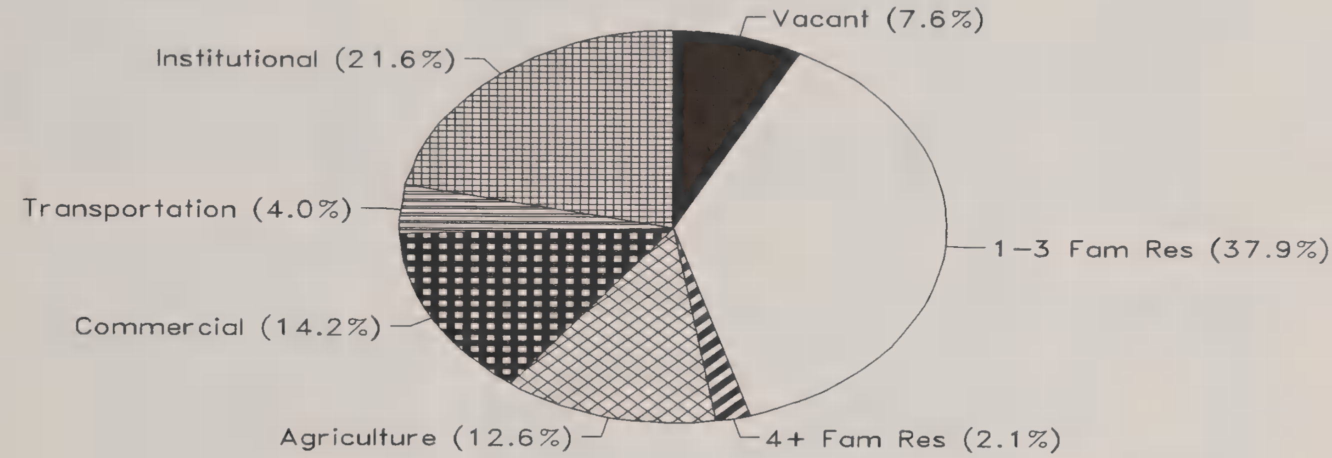

Figure 21. Land use in DuPage County.

the extensive Cook County Forest Preserves, which account for 12 percent of total area in the County (Table 4).

Relations among land use types, AGS, and CSL vary along the urban-rural gradient (Table 4). For most land uses, AGS tends to increase along the urban-rural gradient, while CSL decreases. AGS ranges from 10 to 30 percent near the city center, where highly intensive land uses such as multi-family residential and commercial lands are common. AGS for moderately intensive land uses (e.g., 1-3 family residential, transportation, education) dispersed around the city typically range from 30 to 70 percent. AGS exceeds 70 percent for the least intensive land uses such as vacant/wild, agriculture, parks, and forest preserves. CSL tends to be lowest for land uses that are most hostile to tree growth. Stocking values are usually below 20 percent for transportation, agriculture, and large commercial/industrial land uses. CSL ranges from 20 to 40 percent for other land uses, except for higher values in the forest preserve land use category.

The relative importance of different types of trees and grass also varies with land uses and along the urban-rural gradient. Trees and grass cover types were categorized as 1) street (growing along streets), 2) managed (growing in yards, parks, and other non-street locations where management occurs), and 3) unmanaged (growing in locations where management is minimal). Most trees occurring in land uses of high (see high sq. ft. commercial in Fig. 22) and low (see vacant/wild in Fig. 23) development intensities are unmanaged. Apparently, these trees are largely "volunteers" along property edges, patches of relict forest, and other forms of opportunistic regeneration. In land uses

Table 4
Percentage Area, Tree Cover, Available Growing Space, and Canopy Stocking Levels by Land Use for each Sector.

	Chicago				Cook County				DuPage County			
Land Use	Area %	Tree	AGS	CSL	Area%	Tree	AGS	CSL	Area%	Tree	AGS	CSL
1-3 Fam Res	40	15	40	38	38	24	60	41	41	25	71	36
≥4 Fam Res	8	7	24	27	2	9	36	25	2	10	44	23
Small Comm	7	2	7	27	2	4	17	21	2	1	9	15
Large Comm	18	3	24	12	12	2	32	13	8	1	34	4
Park Comm	0	12	66	18	0	16	74	21	0	6	44	14
Bldg Inst	5	7	42	17	4	6	60	11	3	10	59	17
Park Inst	7	26	77	35	6	17	90	19	7	20	87	24
Forest Inst	2	54	79	68	12	67	93	72	3	75	94	80
Auto Trans	2	4	31	13	2	0	50	1	2	0	30	0
Other Trans	9	2	42	4	2	2	43	21	1	2	60	4
Agriculture	0	0	94	0	13	4	98	24	21	2	98	2
Vacant	3	20	80	24	8	39	92	43	10	32	93	34

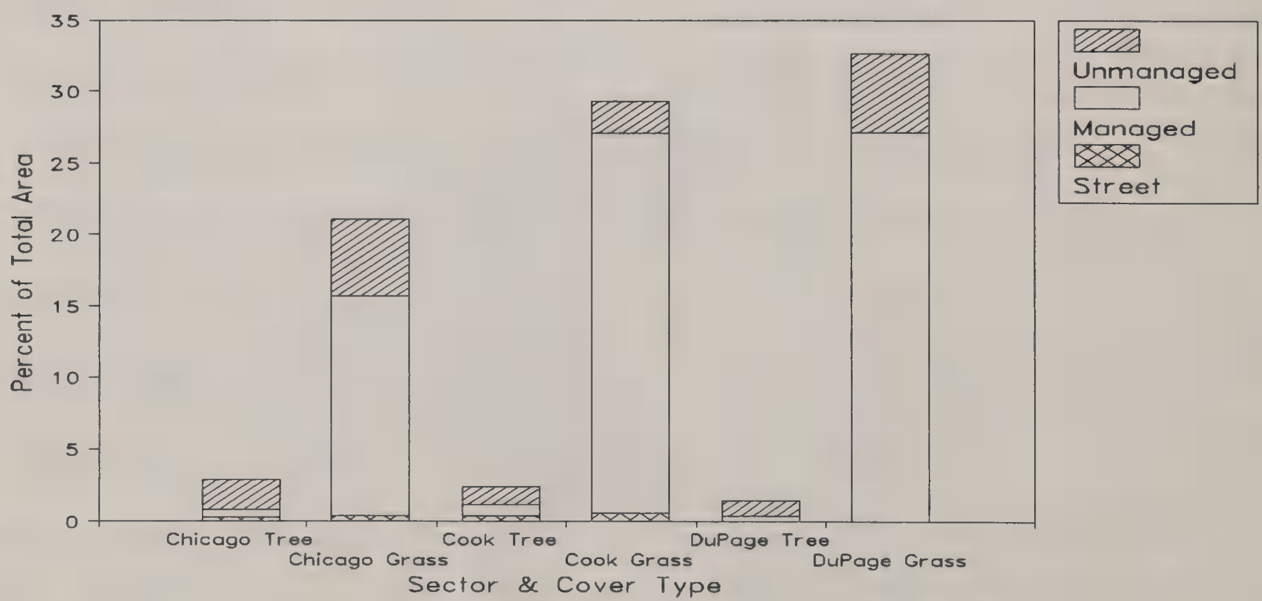

Figure 22. Vegetation cover for large commercial land.

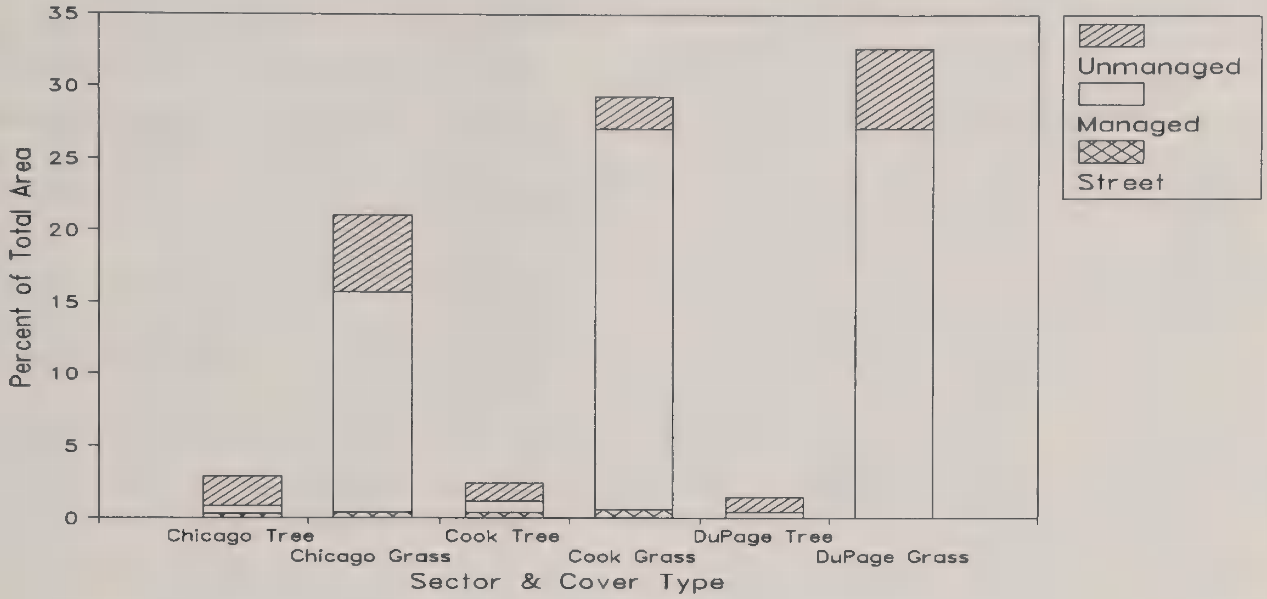

Figure 23. Vegetation cover for vacant/wild land.

of moderate development intensity the importance of street trees diminishes along the urban-rural gradient. In Chicago, street tree cover accounts for half of all tree cover in 1-3 family residential land uses (Fig. 24),but this figure drops to 19 percent in Cook County and 6 percent in DuPage County. Managed trees are the most important tree cover type in Cook County, while unmanaged trees predominate in DuPage County. These trends reflect the apparent restriction on yard trees by the densely built environment in Chicago, the opportunities created for yard trees by larger lot sizes in Cook County, and the important role of tree preservation on newly developed lands in DuPage County.

Although managed grass is more dominant than street and unmanaged grass cover types in most land uses of high and moderate development intensity, its relative importance increases along the urban-rural gradient. In 1-3 family residential land uses in Chicago, managed grass accounts for 79 percent, and street grass is 20 percent, of all grass cover (Fig. 24). Managed grass cover represents 90 and 92 percent of total grass cover in Cook and DuPage Counties, respectively. Unmanaged grass predominates in the lower intensity agricultural and vacant/wild land uses (Fig. 23).

Management Implications

Chicago. In Chicago, a considerable portion of the urban forest resource occurs along streets in residential land uses and CSL appears to be relatively high for street trees. CSL for off-street tree cover is about 20 percent, suggesting that there is ample space for new tree plantings on

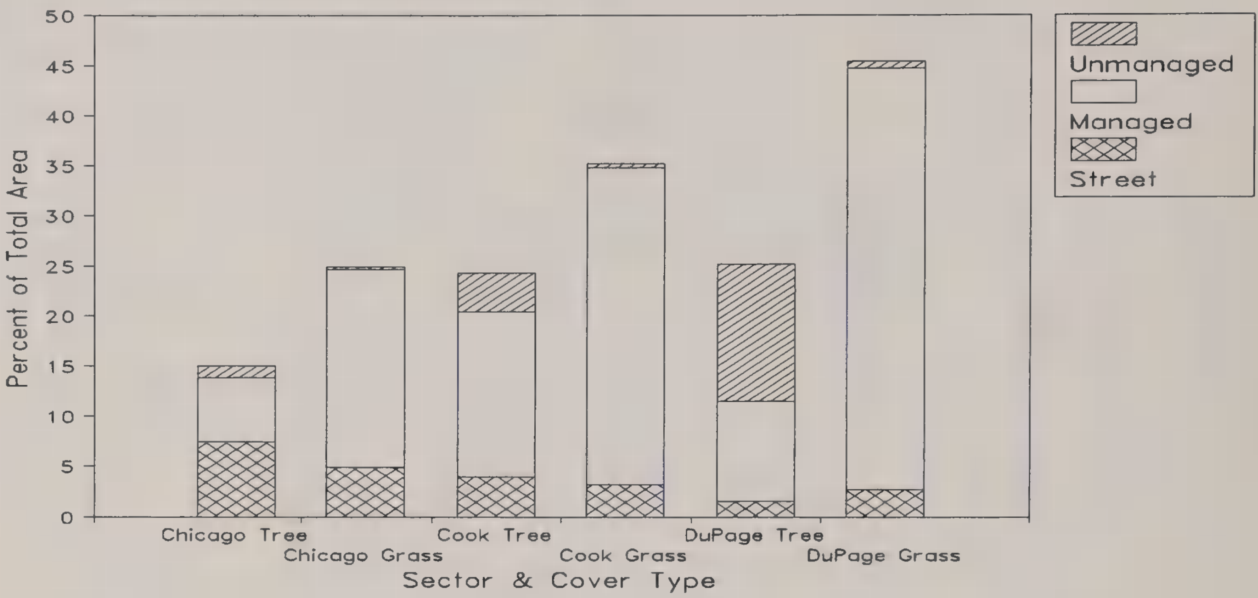

Figure 24. Vegetation cover for 1 to 3 family residential land.

residential properties. However, summer field data will indicate the extent to which additional yard tree plantings are limited by utilities, buildings, and lot configurations. Other land uses with high potential for new tree plantings cover significant amounts of land in Chicago, and have relatively high AGS and low CSL values. Included in this category of land uses are institutional areas dominated by buildings (e.g., schools, hospitals, government offices/libraries), large commercial/industrial lands (e.g., malls, warehouses, manufacturing), and transportation right-of-ways (e.g., highway and railroad).

Cook County. Both tree cover (22.5%) and CSL (33.5%) are higher for Cook County than for other sectors. This result is due in part to the relatively large area covered by well-stocked forest preserves. Although street tree cover in 1-3 family residential land use is less in Cook County than Chicago, CSL for off-street yard trees (39%) is about twice that in Chicago. These findings suggest that the greatest opportunities for new tree plantings exist along streets in Cook County. However, large yard trees growing into streetside space may restrict planting along some streets that are classified as understocked. Other land uses with high potential for tree planting include highway right-of-ways, shopping malls and other large commercial/industrial land uses, and park-type landscapes (e.g., parks, cemeteries, golf courses). Park-type landscapes appear especially understocked (AGS is 90%, CSL is only 18.5%), and generally provide physical environments conducive to tree planting and survival.

DuPage County. Turf is the dominant cover type (46%) for low density residential land in DuPage County. This trend may change in response to increased summer water bills associated with the depletion of available groundwater aquifers by the rapid growth in DuPage County. Because landscape water use is one of the first places consumers look to lower costs, increasing water prices may spur conversion to water-efficient landscapes that incorporate low water use ground covers and trees. Our findings indicate that there is ample space in yards and along streets for increased planting of tree cover that could shade or replace more water consumptive grass cover. Another understocked land use in DuPage County is large commercial/industrial areas. Although AGS (34 percent) is greater in DuPage than Chicago or Cook, CSL is lower (4 percent vs. 12 to 13 percent) for this land use. Field data collected during the summer of 1992 will be used to determine if low CSL is due to low tree densities or larger numbers of immature trees. Planting potential will be higher if tree densities are low. Transportation and park-like landscapes also have high potential for new tree planting. Preservation of existing unmanaged tree cover (e.g., relict forest patches, riparian corridors, woodlots) should also remain a management priority in DuPage County.

SUMMARY

Vegetated surfaces cover 64 percent of the CUFCP study area, and tree cover accounts for about one third of the total greenspace resource. Variations in urban forest cover throughout the region can be related to land use characteristics and a theoretical urban-rural gradient that extends from the city center to rural hinterland. Restrictions on trees diminish along the urban-rural gradient, as reflected by increasing amounts of available growing space and tree cover. In Chicago, where trees are most restricted by the built environment, street trees are the predominant type of tree cover. Potential for new tree plantings appears greatest in yards, highway right-of-ways, and large commercial/industrial lands. Tree cover and canopy stocking levels are relatively high in Cook County. Lower CSL for street trees in Cook County compared to Chicago are compensated for by higher CSL values for off-street managed trees. Park lands have surprisingly low canopy stocking values and may be appropriate targets for new plantings, although additional investigation is required to confirm this observation. Turf grass is the predominant land cover type in DuPage County. Tree cover may increase as recent transplants mature and landscapes become more water-efficient. Unmanaged trees are the most frequent type of tree cover in DuPage County, which attests to the importance of forest preserves, private woodlots, and preservation of forest areas during the development process. Management efforts should seek to continue preservation of existing forest, wetland, and other greenspace resources, as well as to increase tree cover on understocked land uses in DuPage County.

6 ENVIRONMENTAL ISSUES

Chicagoans, like citizens across the United States, are increasingly concerned about the quality of their air and water and the long-term availability of energy and water supplies. Policy makers, natural resource planners, and greenspace managers have recognized that urban vegetation can improve quality of life in our cities. This section explores environmental issues of special interest in Chicago: air quality, climate, energy conservation, and hydrology. Recent research findings and management strategies are reviewed. The potential role of vegetation for environmental improvement is assessed.

AIR QUALITY

Although the air quality of the Chicago region has improved during the past two decades, unhealthy concentrations of pollution continue to occur. For instance, ozone (O_3) levels exceeded federal health standards on 31 days from 1986 through 1990. Excessive levels generally occur on the warmest days during the summer. The CUFCP is one of several studies that are investigating ways to improve the region's air quality. Urban vegetation can mitigate O_3 pollution by lowering city temperatures and directly absorbing the gas. However, many plants emit hydrocarbons which add to O_3 formation (Nowak, 1992). Interactions between urban vegetation, climate, and atmospheric quality are extremely complex. The following section reviews these relationships, the status of other local studies, and the health threats posed by various pollutants to residents of the Chicago region.

Background

Air pollutants are substances which, under certain conditions, can injure humans, animals, plant or microbial life, or property, or otherwise interfere with the use and enjoyment of life or property (Oke, 1987). Air pollution concentrations are affected by local surroundings. Atmospheric inversions can concentrate pollutants; high air temperatures, common in urban areas due to heat island effects, can enhance the production and/or emission of some pollutants; and local winds can disperse or concentrate pollutants.

Vegetation influences air quality by directly intercepting particulates and absorbing gaseous pollutants through leaf stomates. Vegetation also can improve air quality by lowering city temperatures.

The U.S. Environmental Protection Agency (EPA) has established National Ambient Air Quality Standards (NAAQS) which represent the level of air quality necessary to protect public health. Sanctions can be issued against areas that do not meet federal air quality standards and if the state does not submit and enforce an acceptable State Implementation Plan by federal deadlines. These federal sanctions are complex but can be broadly placed in three categories: 1) loss of federal highway funds, 2) loss of section 105-grant money

(federal money for state and local air quality programs), and 3) lowering of permitted emissions for new businesses or revamped existing businesses. In addition, the EPA can invoke a new Federal Implementation Plan that supersedes the State Implementation Plan (Inman, D., Chicago Dep. of Environ., pers. comm., 1992).

Various agencies are involved in the development of State Implementation Plans, air quality ordinances, and the enforcement of air quality regulations in the Chicago area (EPA, Illinois Environmental Protection Agency [IEPA], Cook County Department of Environmental Control [Cook Co. DEC], and the Chicago Department of Environment). Two agencies (IEPA and Cook Co. DEC) monitor and conduct laboratory analyses of local air pollutants. There are 39 air quality monitoring stations in the CUFCP study area: 36 in Cook County (17 in Chicago) and 3 in DuPage County (IEPA, 1991).

Total suspended particles (TSP) and concentrations of sulfur dioxide (SO_2) have been decreasing in Chicago. In the 1960's, annual network averages for the city averaged 123 ug/m^3 (micrograms per cubic meter) for TSP and 113 ug/m^3 for sulfur dioxide (1964-69). During the 1970's, these levels dropped to 85 ug/m^3 for TSP and 39 ug/m^3 for SO_2 (Chicago Dep. of Consum. Serv., 1982). Carbon monoxide (CO) was the major air quality issue from the late 1970's through the mid-1980's. In the late 1980's, major air quality issues in the Chicago region centered around particulates and O_3.

Air quality studies currently being conducted or concluded include: 1) a cancer risk study on emissions of 20 known carcinogens in southeast Chicago (Summerhays, 1989): 2) a similar current cancer risk study by the EPA on the southwest side of Chicago (Rothblatt, S., EPA, pers. comm., 1992): and 3) the Lake Michigan Ozone Study, which is attempting to identify mechanisms of (O_3) formation and transport in a four-state region (Lake Michigan Air Dir. Consort., 1991).

The effect of pollutants may be direct, e.g., toxicity or indirect, the "greenhouse effect." Five common air pollutants to the Chicago region are O_3, particulates, SO_2, CO, and nitrogen dioxide (NO_2). The following section describes each of these pollutants in terms of sources, ambient levels in the Chicago region, pollution effects, and removal mechanisms.

Ozone

Ozone is formed by a photochemical reaction of nitrogen oxides and volatile organic compounds (VOC) in ultraviolet sunlight and moisture. VOCs are a broad class of pollutants encompassing hundreds of specific compounds and are emitted in urban areas primarily from motor vehicles, evaporation of solvents and gasoline, and chemical processing (Off. of Technol. Assess., 1989). Trees also contribute VOCs to the atmosphere through natural plant processes (Tingey and Burns, 1980). Nitrogen oxides arise primarily from the combustion of fossil fuels in urban areas.

Ozone concentrations tend to be highest on hot sunny days because: (1) the

chemical reaction is temperature and sunlight dependent, (2) emissions of precursor chemicals from some sources increase with temperature, and (3) stagnant air that tends to limit pollution dispersion often is associated with high temperatures (Off. of Technol. Assess., 1989). In Chicago, both the urban heat island and lake breeze effects reach full development when insolation is strong and regional winds are light. Lake breezes impede pollution diffusion on about two-thirds of spring and summer days (Lyon, 1971; Cole and Lyons, 1972; Schmid, 1975).

Ozone is a pulmonary irritant affecting respiratory tissues and functions. Exposure to O_3 results in symptoms such as chest tightness, coughing, and wheezing. Alterations in airway resistance can occur in asthmatics and other sensitive individuals, and even in healthy exercising people at short-term concentrations of 0.15 to 0.25 ppm. Exposure to O_3 also can increase susceptibility to bacterial lung infection (IEPA, 1991).

Cook and DuPage Counties exceeded NAAQS of 0.12 ppm (1-hour average) on 31 different days from 1986 through 1990. The highest level occurred in Chicago on July 7, 1988 (0.223 ppm). Of the days when NAAQS were exceeded, 47 percent occurred in Chicago and 96 percent within Cook County (IEPA, 1987-1991).

The reactive nature of O_3 causes it to react rapidly on the surface of leaf mesophyll cells (Smith, 1984). Ozone-induced stress in trees is characterized primarily by leaf or needle discoloration and/or premature leaf loss (Off. of Technol. Assess., 1989). Other physiological effects include growth alterations and reduced yields. Adverse effects on sensitive vegetation have been observed from exposure to photochemical oxidant concentrations of 0.05 ppm for 4 hours.

Major sources for O_3 removal are participation in atmospheric reactions, absorption by soil and vegetation, and removal by surface water (Rasmussen et al., 1975).

Particulates

Particulates are generated primarily by the combustion of fossil fuels, industrial processes, soil erosion, and photochemically produced particles (complex reactions between sunlight and gaseous pollutants) (IEPA, 1991).

Particles enter the human body through the respiratory system. Particles greater than 5 micrometers (um) generally are filtered out by the nose and throat. Particles between 0.5 and 5 um may be deposited as far as the bronchioles in the lungs. Most particles deposited in the bronchioles are removed by cilia within a few hours. Particles less than 0.5 um in diameter may reach and settle in the alveoli (Stoker and Seager, 1976).

Health effects are influenced by particle size, oxidation state, chemical composition, and concentration and residence time in the respiratory system. Particulates have been associated with respiratory diseases (e.g., asthma), cardiopulmonary diseases (heart attacks), and cancer (IEPA, 1991).

From 1986 through 1990, Cook and DuPage Counties have exceeded NAAQS (150 ug/m^3, 24-hour average) for particles less than 10 um (PM10) on 5

different days. All days exceeding NAAQS occurred in Cook County, 40 percent within Chicago. Two townships in Cook County (Lake Calumet and McCook) are moderate non-attainment for PM10. Monitoring for PM10 has been increasing as the national standard for PM10 replaced the national standard for total TSP on July 1, 1987 (IEPA, 1987-91).

Regional TSP levels have exceeded previous NAAQS (260 ug/m^3, 24-hour average) on 19 different days from 1986 through 1990. The highest TSP reading in Chicago was 442 ug/m^3 on October 11, 1989. All days exceeding NAAQS occurred in Cook County, 47 percent within Chicago. For the same period, 18 monitoring stations also exceeded previous annual NAAQS for TSP (75 ug/m^3) 56 percent of the days exceeded were in Chicago; 94 percent in Cook County (IEPA, 1987-91).

Heavy-metal particles, including lead, can be absorbed directly through the plant cuticle and produce a toxic effect, particle accumulation on leaves can result in a strong reduction of photosynthesis (Ziegler, 1973).

Particles are removed from the atmosphere by wet and dry deposition. Dry deposition takes place as a result of sedimentation and impaction on objects. Wet deposition involves rainout (particles serve as nuclei for condensation) and washout (falling rain or snow collects particles on the way to the ground) (Stoker and Seager, 1976).

Sulfur Dioxide

The main source of anthropogenic emissions of SO_2 is fuel combustion from stationary sources, particularly coal (Stoker and Seager, 1976), SO_2 is an irritant of the respiratory system.

Inhalation of SO_2 causes bronchial constriction, resulting in increased resistance to air flow, reduction of air volume and increased respiratory and heart rate, and if can exacerbate preexisting respiratory conditions (IEPA, 1991). The lowest concentration causing a human response (conditioned reflexes centered in the brain cortex) is 0.2 ppm. At 0.3 ppm there is taste recognition; 0.5 ppm: odor recognition; 8 to 12 ppm: immediate throat irritation; 10 ppm: eye irritation; and 20 ppm: immediate coughing (Stoker and Seager, 1976).

The NAAQS for SO_2 (0.14 ppm, 24-hour average) has been exceeded only once from 1986 through 1990 for the Chicago region. The highest daily SO_2 level (0.169 ppm) during the same period occurred on April 8, 1986, in Bedford Park, Cook County.

Sulfur dioxide is readily absorbed by trees and rapidly oxidized to sulphate in their mesophyll cells (Smith, 1984). Short-term exposure to high concentrations of SO_2 can cause acute injury characterized by dead areas of leaves; lower concentrations over longer periods can cause chronic injury characterized by leaf chlorosis, SO_2 injury often is restricted to localized areas downwind of point sources (Skelly et al., circa 1985).

The major identified sinks for this gas are wet deposition (contributes to acid rain), chemical reactions (dry deposition), and absorption by soil, water, stone, and vegetation (Rasmussen et al., 1975).

Carbon Monoxide

Motor vehicles are the major anthropogenic source of CO in the United States (Stoker and Seager, 1976). Carbon monoxide is absorbed by the lungs and reacts with hemoglobin to form carboxyhemoglobin (COHb), which reduces the oxygen carrying capacity of blood. The higher the atmospheric concentration of CO, the higher the percentage of hemoglobin bound in the form COHb and the more serious the health effects (IEPA, 1991).

At COHb levels of 1 to 2 percent there is some effect on behavioral performance; at 2 to 5 percent effects on the central nervous system (e.g., discrimination of time intervals); 5 to 10 percent: changes in cardiac and pulmonary functions; and 10 to 80 percent: headache and fatigue through coma, respiratory failure, and death (Stoker and Seager, 1976).

From 1986 through 1990, CO levels in Chicago have exceeded the NAAQS of 9 ppm (8-hour average) only once, on June 17, 1987 (10 ppm). Chicago was previously non-attainment for CO, but was removed from that list when in 1990, indicating an improvement

Studies of existing ambient levels of CO do not indicate adverse effects on vegetation (IEPA, 1991). Carbon monoxide within leaves can be oxidized to CO_2 or fixed to serine (Smith, 1984). Major sinks for CO are soil absorption and chemical oxidation (Rasmussen et al., 1975).

Nitrogen Oxides

When combustion temperatures are high (e.g., automobile engines), atmospheric nitrogen (N_2) may combine with molecular oxygen to produce various oxides of nitrogen (NO_x). Of these, nitric oxide (NO) and NO_2 are the most important air pollutants (IEPA, 1991). The majority of emitted NO_x is in the form of NO: however, NO oxidizes to NO_2 in the atmosphere (Stoker and Seager, 1976).

Nitrogen dioxide is about four times more toxic than NO (Stoker and Seager, 1976). It can impair one's adaptation to dark at concentrations as low as 0.07 ppm and increase airway resistance, respiratory rate, sensitivity to bronchoconstrictors, and susceptibility to respiratory infections. NO_2 is a deep lung irritant and can produce pulmonary edema if inhaled in sufficient concentrations (IEPA, 1991). NO_x may also contribute to the formation of O_3. The NAAQS for NO_2 (0.053 ppm, annual average) has not been exceeded in Chicago from 1986 through 1990.

Nitrogen dioxide dissolved in water yields nitrite and nitrate ions in solution. The latter can be reduced to ammonia in leaf cells (Smith, 1984). High concentrations of NO_2 can produce symptoms similar to SO_2 damage. NO_2 can also suppress growth (Darly, 1971).

Nitrogen dioxide is removed primarily by precipitation (contributing to acid rain) but can also be absorbed by vegetation and soils or participate in photochemical reactions to form aerosols (Rasmussen et al., 1975).

Greenhouse Gases

Various gases can contribute to the greenhouse effect and its potential for global warming. These gases include CO_2, O_3, NO_x, methane, and

chloroflourocarbons. The predominant greenhouse gas is CO_2, the major anthropogenic source of which is combustion of fossil fuel. This contributes approximately 5 billion metric tons of carbon to the atmosphere annually. Levels of atmospheric carbon are increasing at the rate of 3 billion metric tons per year; the difference is primarily due to the removal of atmospheric carbon by the oceans (Schneider, 1989). In Chicago alone, it is estimated that carbon emissions due to automobiles totals approximately 1.6 million metric tons annually.

Because they sequester atmospheric carbon through their growth process and conserve energy in urban areas, trees have been suggested as one means of combating increasing levels of atmospheric carbon. Analysis of the urban forest in Oakland, California, revealed it currently stores approximately 145,000 metric tons of carbon (Nowak, 1991). Future growth and planting of trees can add to that storage total if the amount of carbon sequestered due to growth and planting remains greater than the amount of carbon lost due to mortality (Nowak and Rowntree, 1991).

Akbari et al. (1989) estimated that the establishment of 100 million mature urban trees around residences and commercial buildings would save 8.2 million metric tons of carbon annually due to energy conservation. In the Chicago region, 79 percent of the energy that is generated is supplied by nuclear power plants; therefore, the reduction of carbon due to energy conservation in Chicago will be lower than for cities with mostly fossil fuel power plants. However, peak load savings will significantly reduce emissions because peak demand is met with power generated by fossil fuels.

Implications for the Future

The major air quality issues of the 1990's are likely to be O_3, particulates, and atmospheric CO_2. Increased atmospheric CO_2 likely will lead to increased air temperatures and exacerbate O_3 problems. The major emission sources for all three of these pollutants are automobiles and industrial processes. Automobiles are major sources of nitrogen oxides and hydrocarbons, which form O_3. They also are a major source of particulates and emit carbon to the atmosphere at the rate of approximately 5 pounds per gallon (8.6 kilograms per liter) of gasoline (Akbari et al., 1989). Various industrial processes emit these same pollutants.

As development spreads outward around Chicago, the key issue of air quality will likely be automobile emissions. Development that decreases commuting distances and dependence on the automobile, or technologies that decrease automobile emissions of nitrogen oxides, hydrocarbons, particulates, and carbon likely will have a great impact on air quality.

Land use development and conversions in Cook and DuPage Counties also will affect air quality. The development of vegetated areas could have negative impacts on air quality by reducing vegetative and soil absorptive capacity and increasing emissions and ambient air temperatures.

Proper management of vegetation in urban areas has the potential to improve air quality. Vegetation can intercept particulates, absorb various air pollutants, store atmospheric carbon, and reduce

ambient air temperatures. However, vegetation also emits hydrocarbons that can enhance ozone formation. The CUFCP will analyze the overall impact of urban trees on air quality in the Chicago region.

CHICAGO'S URBAN CLIMATE

The climate of Chicago is marked by its variability. Seasonal temperature extremes are due to Chicago's northern latitude and interior continental location, while the easterly procession of high- and low-pressure fronts can cause extreme changes day to day (Cutler, 1976). Within this large or mesoscale climate are smaller urban climates that reflect local differences in the patterns of streets, buildings, and greenspace. For example, an average temperature elevation of 3.3°F (1.85°C) in the city compared to surrounding rural areas reflects the influence of the area around Midway Airport on Chicago's urban heat island. This heat island effect is primarily due to increased heat storage by buildings and paving in cities. In Chicago, the urban heat island is complicated by the presence of Lake Michigan. Lake breezes bring cool, moist air as many as 30 miles (50 km) inland, thereby moderating urban warming. Lake breezes and the urban heat island also influence the amounts and patterns of regional precipitation. Anomolously high levels of precipitation in downwind La Porte, Indiana, have been associated with Chicago's urban climate (Changnon, 1968).

Although there has been no systematic overview of Chicago's urban climatology, researchers associated with the CUFCP will address this deficiency by analyzing synoptic conditions using data from climatic stations throughout the region. The following sections include general information on the structure and implications of urban heat islands and summarize research findings related to Chicago's heat island.

Structure of Urban Heat Islands

Warmer air temperatures in cities compared to surrounding rural areas is the principal diagnostic feature of the urban heat island. Human-made alterations of the urban surface result in diverse microclimates, whose aggregate effect is reflected by the heat island (Landsberg, 1981). Buildings, paving, vegetation, and other physical elements of the urban fabric are the active thermal interfaces between the atmosphere and land surface. Their composition and structure within the urban canopy layer, which extends from the ground to about roof level, largely determine the thermal behavior of different sites within a city (Goward, 1981; Oke, 1987). Thus, urban heat islands can be detected at a range of scales, from the microscale of a shopping center parking lot to the mesoscale of an urbanized region (McPherson, 1991).

The structure of the urban heat island has been well documented from climatological studies of cities around the world (Chandler, 1965; Landsberg, 1981; Oke, 1986). Differences in urban and rural temperatures are greatest and the spatial and temporal qualities of these anomalies most apparent during clear and calm summertime conditions. The horizontal structure of a hypothetical heat

island (Fig. 25) is characterized by a "cliff" that follows the city's perimeter and is steepest along the windward boundary (Oke, 1982). This sharp temperature gradient leads to pulses of cool air flowing into the city at night. Intraurban heat islands and "cool islands" reflect localized effects of differences in building density and surface cover. Temperatures in urban parks can be 1.8 to 5.4°F (1 to 3°C) cooler than outside (Fig. 26), and their influence can extend several hundred yards beyond the park boundary (Chandler, 1965; Herrington et al., 1972; Oke, 1989). Urban-rural temperature differences are usually greatest, 5 to 15°F (-15 to -9°C), in early evening near the city core. However, warmest daytime temperatures often occur outside the core in a zone with lower buildings and more exposed pavement (Tuller, 1973). Advection due to winds causes the warmth of the city to be carried downwind.

Analysis of temporal differences shows that the intensity of the urban heat island is greatest at night and is due pri-

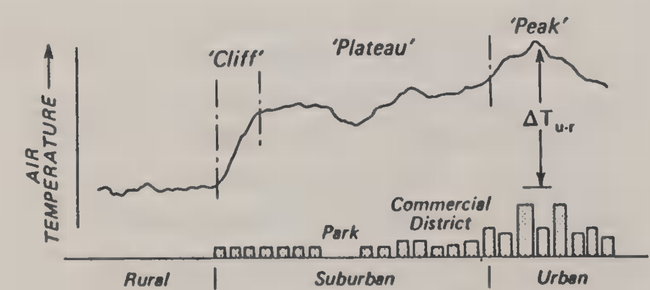

Figure 25. Generalized cross-section of a typical urban heat island (Oke, 1987).

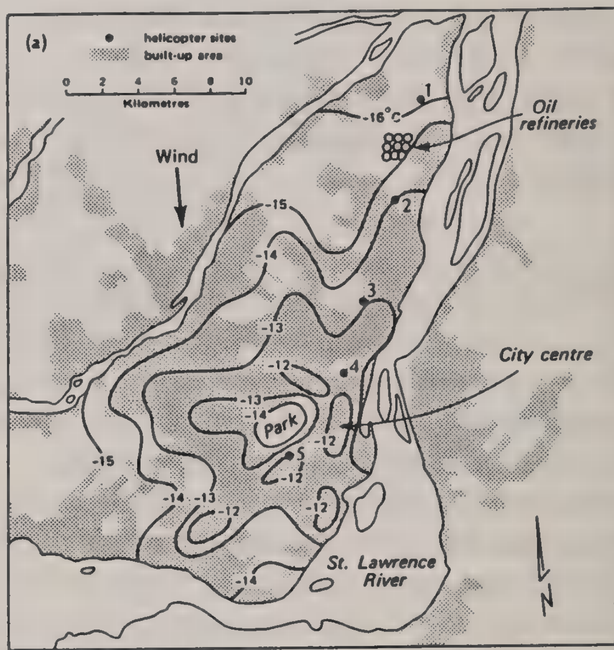

Figure 26. Urban heat island in Montreal at a.m. with winds from the north (Oke, 1987).

marily to differences in urban-rural cooling (Oke, 1982). Nocturnal anomalies in urban air temperatures of 5 to 10°F (-15 to -12°C) are typical compared with 1° (.6°C) daytime anomalies (Goward, 1981). At sunset, rural areas begin to cool rapidly whereas urban areas remain warm and then cool at a slower rate. Different urban-rural cooling rates at sunset produce maximum heat island intensities 3 to 5 hours later. At sunrise, urban areas begin to warm relatively slowly, sometimes producing urban "cool islands" during the morning.

Under calm conditions, a nocturnal rural/urban breeze system that develops modifies the heat island's vertical structure by creating an urban heat dome. Downwind heat plumes can extend over rural

areas for considerable distances. The vertical extent of nocturnal anomalies in air temperature is only 2 to 3 times building height compared with more than one-half mile during the day. Enhanced turbulent mixing of the atmosphere during daytime is primarily responsible for this urban impact on the atmosphere (Duckworth and Sandberg, 1954).

Implications of Urban Heat Islands

Urban temperatures have been increasing in cities around the world. Comparisons of temperature data from paired urban and rural weather stations suggest that the recent warming trends are due to the heat island effect rather than changes in regional weather. For example, data from 31 California cities show a warming rate of 0.7°F (0.4°C) per decade since 1965 (Akbari et al., 1992). Additionally, scientists project a greenhouse warming rate of about 0.5°F (0.3°C) per decade, which could accentuate effects.

Research findings (Akbari et al., 1992) for U.S. cities with populations larger than 100,000 indicate that peak cooling loads increase by about 1 percent for every 2°F (1.1°C) increase in temperature. Approximately 3 to 8 percent of the current demand for electricity for air conditioning in the United States is used to compensate for the heat island effect because city temperatures have increased by about 2 to 4°F (1.1 to 2.2°C) since 1950. Scientists at Lawrence Berkeley Laboratory (Akbari et al., 1988) estimate that the total national cost to offset summer heat island effects on electricity is about $1 million per hour, or more than $1 billion per year (5 percent of total air conditioning costs).

Urban heat islands can accentuate global warming because warmer temperatures result in greater demands for cooling. Coal burning power plants release about 1 lb (0.45 kg) of carbon per kWh of electricity they generate. Therefore, mitigating urban heat islands can indirectly reduce emissions of CO_2 at power plants as well as concentrations of atmospheric CO_2. Implementation of large-scale urban tree planting and the use of light-colored surfaces have the potential to conserve about 2 percent of the total production of carbon in the United States (Akbari et al., 1988).

Concentrations of urban O_3 are enhanced by increases in ambient temperature (Cardelino and Chameides, 1990). One study found that the incidence of smoggy days increased by 1 percent for each 2°F (1.1°C) increase in temperature (Taha, in press). Because many large cities have a smog problem and smog concentrations are sensitive to small increases in temperature, controlling urban heat islands is one means of improving air quality.

Urban heat islands can have numerous other adverse effects on the physical and psychological well-being of city dwellers. Heat-aggravated illness and death are related to increased cardiovascular diseases that weaken one's resistance to heat. Unnaturally high heat loads can directly and indirectly reduce life expectancy (Weihe, 1986).

Research on Chicago's Urban Heat Island

Two studies of the Chicago heat island compared 20 years of temperature and relative humidity recorded at Midway Airport, located within the city and 8 miles (13 km) west of Lake Michigan, and at Argonne National Laboratory, a rural site 14 miles (23 km) southwest of Midway Airport (Ackerman, 1985, 1987). Diurnal and seasonal cycles were studied, as were modifications by local weather conditions.

Seasonal differences show that the heat island is greatest during June through September (Fig. 27). In August, temperature differences of 5.4°F (3°C) or more occurred 20 percent of the time. The average annual magnitude of the urban heat island is 4.3°F (2.4°C) when calculated using daily minimum temperatures.

The diurnal cycle of Chicago's urban heat island follows a pattern similar to that noticed in other cities, largely reflecting differences between rates of cooling and heating in response to the solar cycle (Fig. 28). Isopleths (temperature-difference contour lines) tend to parallel and cluster around the sunrise and sunset lines, indicating greatest differential rates of temperature change. Because of their surface characteristics, Chicago's urban areas are slower to warm and cool than rural areas. The bimodal seasonal cycle during sunlit hours is shown in Figure 29. Two nearly equal minima are evident in spring and autumn, and maxima in August and January. During the evening, a strong summertime heat island is apparent, with a secondary maximum in January-February.

Breezes from Lake Michigan influence urban temperatures. The summertime cooling effect is most pronounced

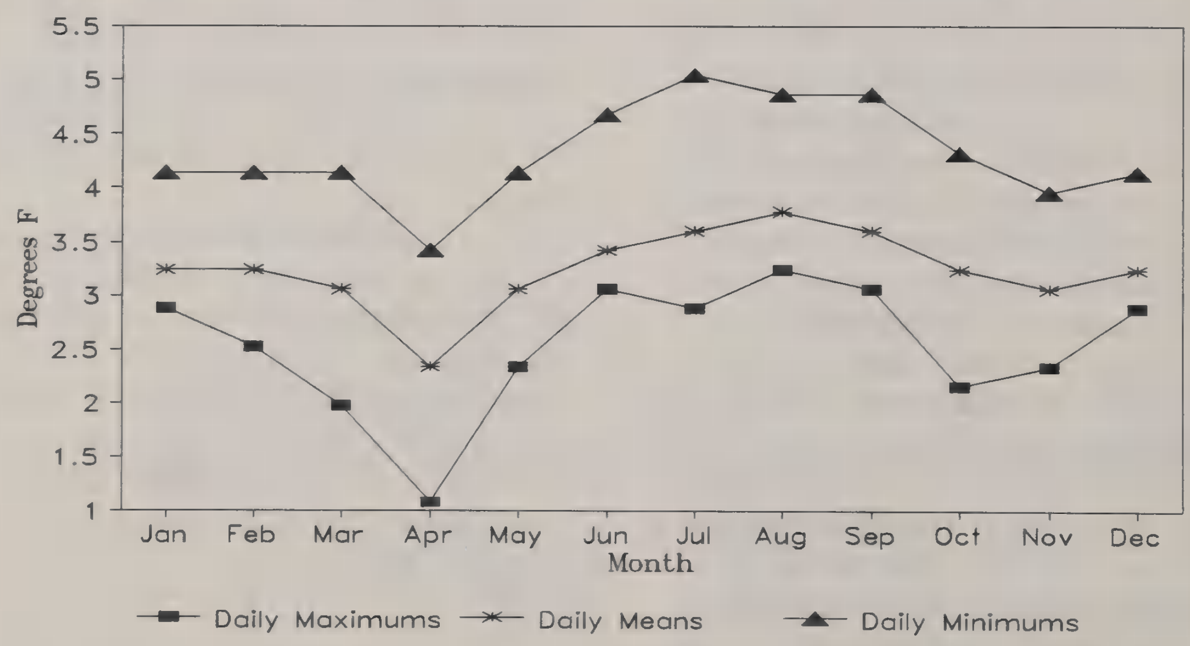

Figure 27. Seasonal variation in average urban-rural differences (Midway Airport-Argonne National Laboratory) in daily maximum, mean, and minimum temperatures (From Ackerman, 1985).

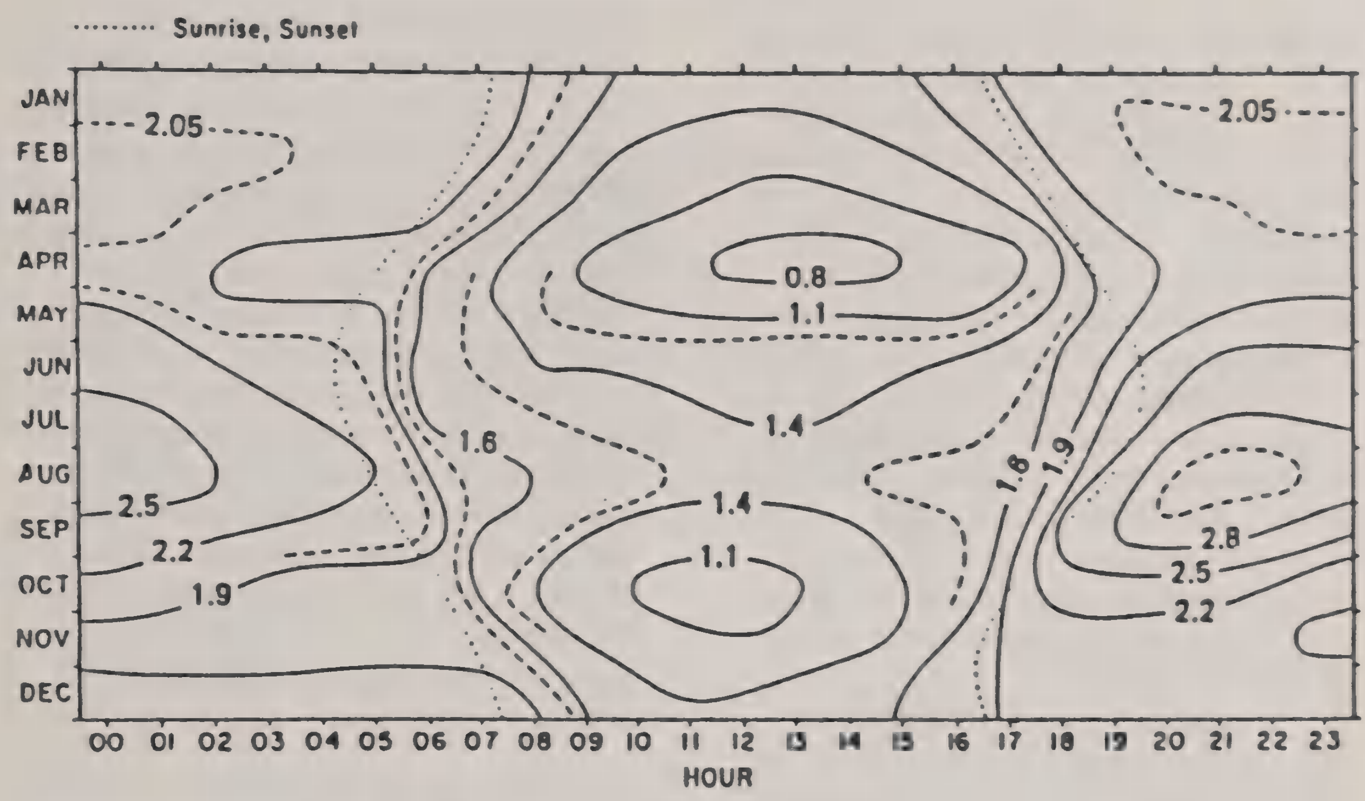

Figure 28. Contours of the average hourly differences (°C) between the temperatures at Midway Airport and Argonne Laboratory, as a function of month and time (CST) (Ackerman, 1985).

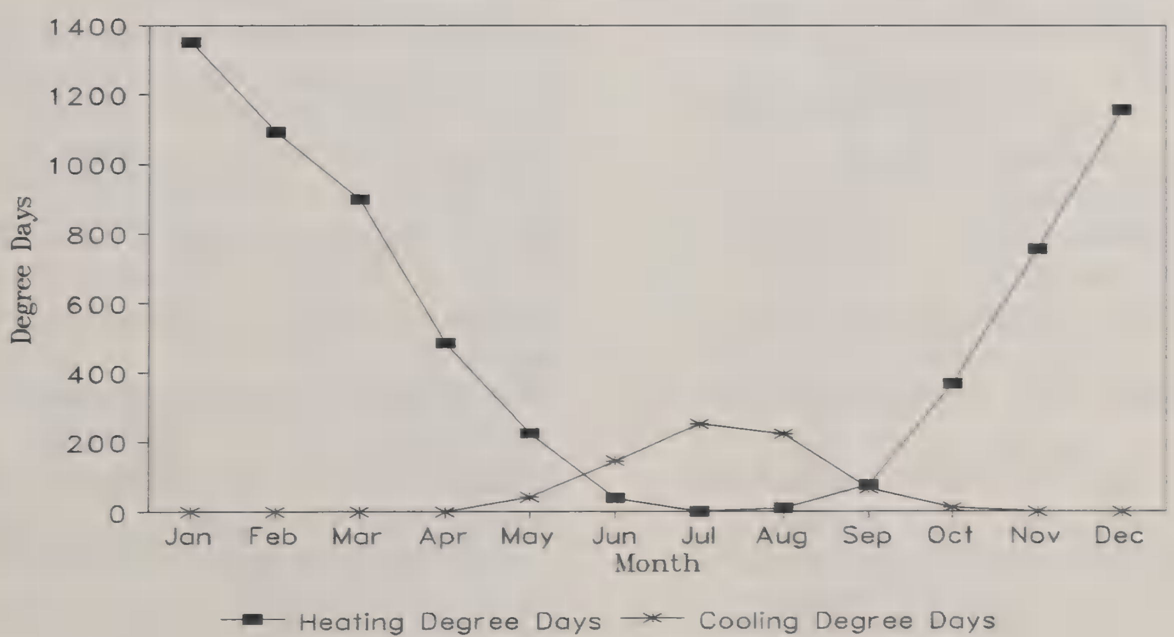

Figure 29. Heating and cooling degree-days for Chicago.

during afternoons and evenings. Systematic lake breezes were identified on 36 percent of 307 summer days, reaching as far inland as Midway Airport in 40 percent of those occasions (Lyons, 1972). A comparison of temperatures at Midway and climate stations closer to Lake Michigan revealed cooler summer and warmer winter temperatures at locations closer to the lake (Ackerman, 1985). Compared to temperatures at Midway, temperatures in the downtown business district, which is within 1 mile (1.62 km) of Lake Michigan, are expected to be slightly cooler during the warm season, and about 2°F (1°C) warmer during the cool season (Ackerman, 1985).

In general agreement with other heat island research (Landsberg, 1981), the Chicago heat island is largest on summer evenings during clear, calm conditions (5.4°F, 3°C) and weakest during cloudy, windy hours (1.4 F°, .8°C). On average, temperatures at Midway Airport were 3°F (1.85°C) higher than at rural Argonne. The extent to which cool summer lake breezes influence the urban heat island is not well known, but temperatures within 1 mile (2 km) of the lakefront are likely to be the most modulated. The relative humidity in urban Chicago is lower than in surrounding rural areas most of the time (Ackerman, 1987), however, this may be due to higher urban temperatures rather than lower urban water vapor. These findings suggest that there is ample opportunity to mitigate the urban heat island effect and conserve energy through the practice of urban forestry in Chicago.

ENERGY CONSUMPTION FOR SPACE HEATING AND COOLING

The amount of energy required to heat and cool buildings depends on the their thermophysical properties, occupants' behavior, and the local climate. Chicago's urban forest influences energy use by shading buildings, moderating temperatures, and changing air flow. Greenspace moderates the Chicago heat island, reducing cooling energy use and emissions of CO_2 from power plants. The following section presents energy use data concerning air conditioning and heating in the CUFCP study area. Research findings on the ability of trees to mitigate Chicago's summer urban heat island and winter heating are reviewed.

Space Heating Energy Use

Chicagoans heat their homes for about eight months (October - May) and require cooling for the remaining four months (June - September). The relative importance of heating is reflected in degree-day information. Degree-days indicate energy requirements over the long term; one degree-day accumulates for every degree the outside temperature is below or above 65°F (18°C) for a 24-hour period. On average, there are 6,455 heating degree-days and 740 cooling degree-days in Chicago (Fig. 30).

Peoples Gas supplies natural gas to heat buildings in the City of Chicago, while Northern Illinois Gas supplies DuPage County. On average, 1,510 and 1,444 therms (1 therm = 100,000 Btu) are consumed annually per dwelling unit in Chicago and DuPage County, respectively. Typical annual residential expenditures for

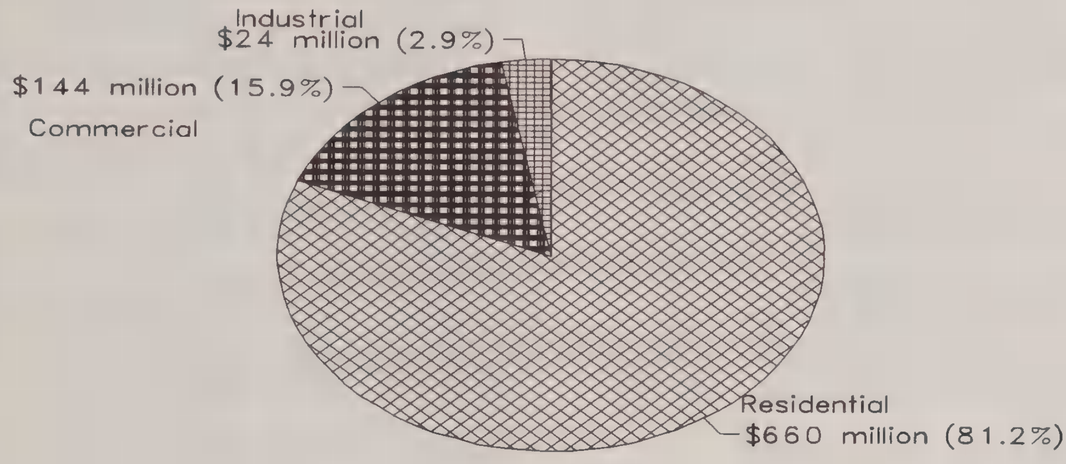

Figure 30. Projected 1991 natural gas sales for space heating in Chicago and DuPage County.

natural gas are $755 ($0.50 per therm) and $592 ($0.41 per therm) for households in Chicago and DuPage.

According to Peoples Gas and Northern Illinois Gas, more than 95 percent of the occupied residential buildings are heated with natural gas. Gas used for space heating accounts for 74 and 67 percent of total annual residential consumption in Chicago and DuPage, respectively, with most of the remainder used to heat water. Natural gas consumed for heating usually is greatest during January, averaging 232 therms ($116) per Chicago residence for the month. Total 1991 sales by Peoples Gas for residential heating alone were 109 trillion cubic feet, worth $568.3 million. DuPage County sales in 1991 by Northern Illinois Gas were 30.4 trillion cubic feet ($117 million).

Percentages of natural gas sales by Peoples Gas for space heating are less for the commercial (67 percent) and industrial (30 percent) sectors than the residential sector. Peoples Gas's 1991 sales for space heating to commercial and industrial customers totaled 55 trillion cubic feet ($166.4 million) and 38 trillion cubic feet ($67.8 million), respectively. Although data on commercial and industrial sales by end use is not available from Northern Illinois Gas, similar percentages can be assumed. Thus, more than $800 million (193 trillion cubic feet) are spent annually for natural gas to heat residential, commercial, and industrial buildings in Chicago and DuPage County (Fig. 30).

Air Conditioning Energy Use

Electricity for air conditioning in Cook and DuPage Counties is provided by Commonwealth Edison (Comm Ed). Nuclear power is the primary source of Comm Ed power, accounting for 79

percent of supply on average. However, during peak days when air conditioning loads are greatest, more power is generated with fossil fuels. Coal (20 percent) and natural gas (1 percent) are fossil-fuel based power sources. Emissions of CO_2 from Comm Ed power plants total about 21 million tons (191 billion kg) annually. Peak demand for electricity occurs when temperatures are high and cooling requirements greatest. During the past 15 years, the peak demand has ranged from July 8 to September 8.

Approximately 66 percent of Comm Ed's residential customers are located in Cook County; and they account for 58 percent of sales. DuPage County residents represent 9 percent of the customer total and 10 percent of sales. Hence, electricity use per customer is relatively higher in DuPage than in Cook County. This fact also is reflected in average electricity use for a summer month, which is 411 kWh for Chicago residents and 590 kWh for all customers. Assuming consumption of 500 kWh during a summer month, the average cost to residential customers would be about $60 ($0.12 per kWh).

According to Comm Ed's 1984 Residential Air Condition Saturation Survey, 38.4 percent of its customers had central air conditioning and 36.4 percent had room air conditioning. Central air conditioning is becoming more common in new home construction. Thus, despite a relatively short cooling season, more than 75 percent of the housing stock uses electricity for air conditioning.

Each central and room air conditioning system is projected to annually use 1,800 kWh ($216) and 490 kWh ($59), respectively, according to Comm Ed's 1984 Conditional Demand Study. Assuming some homes have more than one room air conditioner and increased use of central air conditioning in new homes, about 15 percent of Comm Ed's total residential electricity sales is for air conditioning. This amounts to approximately 2 trillion watt hours or $215.5 million in annual electricity sales for residential air conditioning in the CUFCP study area.

Although air conditioning end use data are not available for Comm Ed's small commercial/industrial and large commercial/industrial customers, values of 12 and 5 percent have been used in other studies (Akbari et al., 1988). Assuming these values for Comm Ed, annual air conditioning sales are projected to be 1.8 trillion watt hours ($144.3 million) for small commercial/industrial and 75 gigiwatt hours ($45.2 million) for large commercial/industrial customers. Overall annual electricity consumption for air conditioning is projected to be 4.6 trillion watt hours, worth $405 million in sales (Fig. 31).

Energy Conservation Through Urban Forestry

The energy saving potential of trees and other landscape vegetation has been measured and documented (Heisler, 1986; McPherson et al., 1989; Meier, 1990; Parker, 1989; McPherson, 1990). Vegetation can mitigate summer urban heat islands directly by shading heat-absorbing surfaces, and indirectly through evapotranspirational (ET) cooling. In a review of studies that measured temperature reduc-

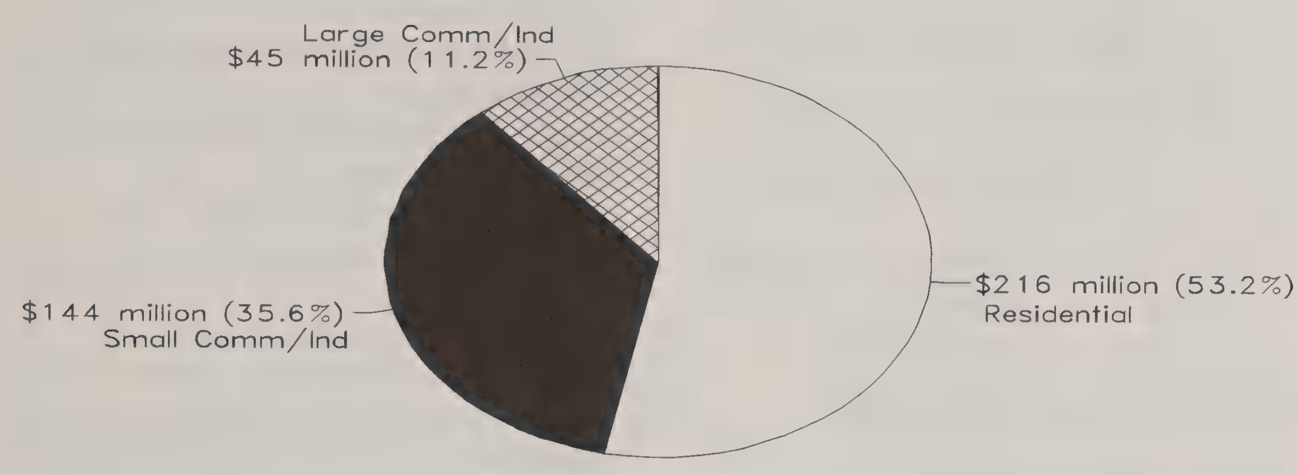

Figure 31. Projected 1990 electricity sales for air conditioning in Cook and DuPage Counties by Commonwealth Edison.

tions, Meier (1990) reported that vegetation consistently lowered wall-surface temperature by about 30°F (17°C); savings in air conditioning ranged from 25 to 80 percent. The extent to which measured reductions in surface temperature and cooling savings can be attributed to direct shading of buildings versus ET cooling is not clear. In most circumstances, the impact of one or several trees on ambient temperatures and cooling load will be small compared to the shading effect. Cool air produced in the tree crown is dissipated by the much larger volume of air moving through the tree. However, large numbers of trees and expansive greenspaces can reduce local air temperatures by 1 to 9°F (.6 to 5°C) and the advection of this cool air can lessen the demand for air conditioning (O'Rourke and Terjung, 1981; Oke, 1989).

Results from computer simulations (Akbari et al., 1988) for three trees around an unshaded residential home in Chicago showed that shade alone reduced annual and peak cooling energy use by 31 percent (583 kWh) and 21 percent (0.67 kW), respectively. Assuming current electricity rates, reduced cooling energy use amounts into an annual savings of about $70 for a Chicago-area household with central air conditioning. Although the combined effects of shade and ET cooling were not simulated for Chicago, ET cooling accounted for about 70 percent of the total cooling energy savings from trees in other cities. Hence, one can infer that large-scale plantings of well-placed trees around buildings in Chicago could substantially reduce air conditioning energy use beyond the computer projections.

Effects of urban vegetation on natural gas consumption for space heating can be beneficial or deleterious depending on tree placement and species selection. Heating savings are largely due to reductions in windspeed, which in turn, reduces the amount of cold outside air that infiltrates a house. In one residential neighborhood, where houses reduced windspeed by about 24 percent, scattered trees reduced windspeed up to an additional 46 percent (Heisler, 1989). Even during winter when deciduous trees are bare, windspeed reductions averaged 50 to 90 percent of reductions in summer.

Computer simulations (Heisler, 1991; McPherson et al., 1988) and building energy measurements (DeWalle et al., 1983) confirm that windbreak plantings around unprotected homes can reduce annual heating costs by 10 to 30 percent. Assuming a conservative savings of 15 percent due to vegetation, an annual savings of $83 (167 therms) in heating energy is likely for a typical Chicago household. However, winter shade on south-facing surfaces can increase heating costs, especially in mid- and high-latitude cities. For example, annual cooling and heating costs for typical home in Madison, Wisconsin, increase from $671 for an energy-efficient planting design to $700 for no trees, to $769 for trees that block winter sunlight and provide little summer shade (McPherson, 1987). Therefore, although reductions in windspeed from landscaping can result in substantial heating savings in Chicago, care must be taken to avoid blocking winter sunlight.

URBAN HYDROLOGY

Studies of rainfall patterns around cities indicate that the urban atmosphere can modify precipitation significantly. City air contains more small particles to which water vapor can attach than the cleaner air of surrounding rural areas. The uplift of particles by the "urban plume" and the time required for droplets to form and grow suggest that enhanced rainfall is likely downwind of the city rather than within it (Oke, 1987). Summertime precipitation around St Louis displays this pattern (Changnon et al. 1971) (Fig. 32). Urban-induced increases in rainfall can add to flooding and costs for stormwater management. Urban greenspace can mitigate this by reducing the amount of atmospheric particles, intercepting rainfall before it contributes to

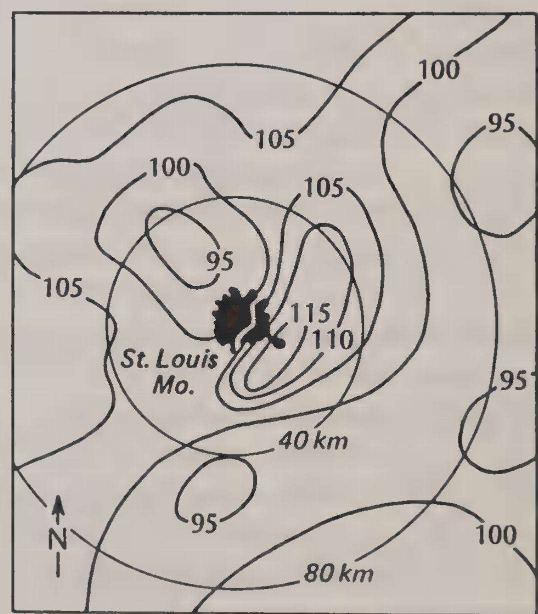

Figure 32. Average rural/urban ratios of summer rainfall in the St. Louis area for 1949-68 (Oke, 1987 after Changnon et al., 1971).

overland flow, and storing water in the soil and retention/detention basins (McPherson, 1991). The following section summarizes research findings on urban-induced rainfall around Chicago and current stormwater management practices and issues.

Urban-Induced Increases in Rainfall and Flooding

The first extensively investigated case of unusually high amounts of rainfall downwind of a city involved La Porte, Indiana, located 25 miles (40 km) southeast of Chicago. From 1940 through the mid-60's rain and thunder values for La Porte were at 30 to 40 percent higher than surrounding values (Fig. 33). In seeking a cause for this anomaly, scientists found a relation between rainfall in La Porte and smoke-haze days in Chicago (Changnon et al., 1979). Analysis of more recent data (1966-78) indicate that the La Porte anomaly has largely disappeared. Causes of the change are thought to relate to decreasing emissions of pollution by industry in the Chicago-Gary area during the past 30 years. Another possible explanation is that the continued growth of Chicago has led to a broader but less well-defined effect. Others speculate that changes in atmospheric circulation patterns in the 1960's caused the anomaly to move to an ungaged area over Lake Michigan. Large-scale circulation changes such as might be associated with global warming could be expected to alter precipitation patterns in the Chicago region.

Historical studies of Chicago-area rain indicate that there are localized influences on the distribution of rainfall within the city as well as downwind. For example, when well-organized (squall line and cold front) heavy rain systems occur, the center of Chicago generally receives the most rainfall (Fig. 34). This summer-season anomaly over the central urban portion of Chicago is most likely due to urban influences rather than lake effects. On average, Chicago receives about 15 percent more rainfall in summer than would occur without the city. There are more heavy rain events (more than 1 inch, 2.54 cm) and more rainfall per heavy rain event in the city than surrounding rural

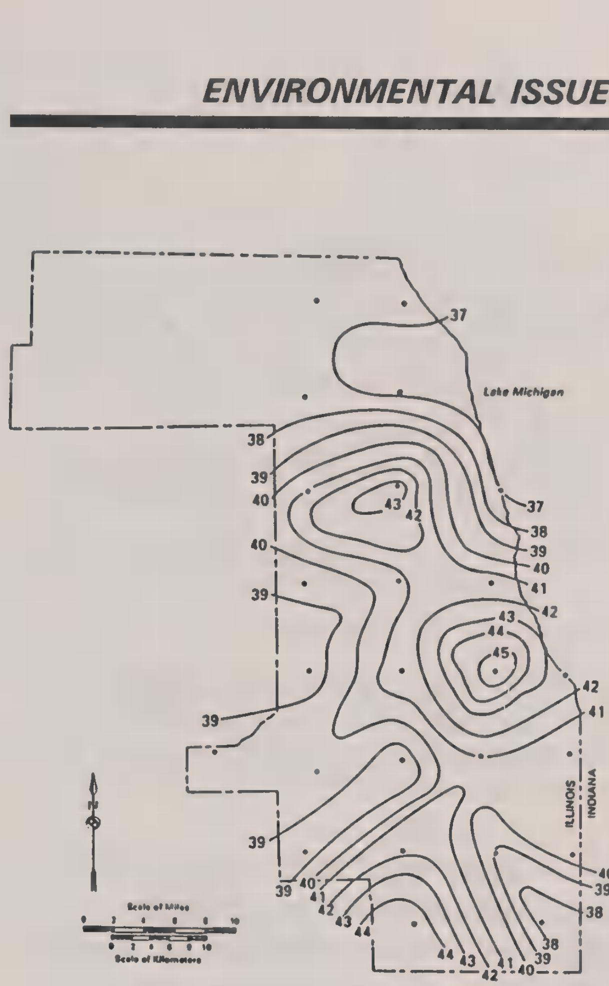

Figure 33. Precipitation pattern (inches) for the 1990 water year in Chicago. Dots indicate sites of the recently installed raingage network (Peppler, 1991).

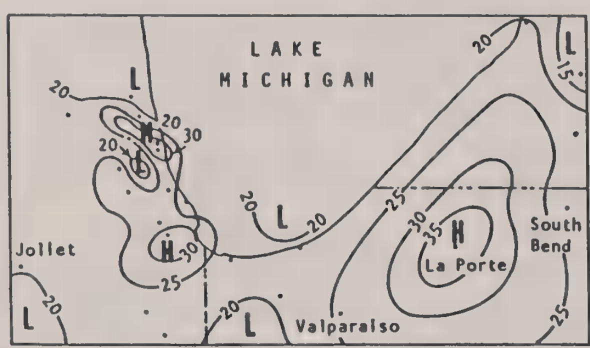

Figure 34. Frequency of heavy (more than 2 inches) daily rainfalls in the Chicago-La Porte areas based on 1949-68 period (Changnon et al., 1979).

areas (Changnon, 1980). For instance, analysis of heavy rain events during 1949-75 indicated average rainfall amounts of 2.3 inches (5.8 cm) in the city and 1.5 inches (3.8 cm) in the countryside. An analysis of 46 heavy rain events (1 inch or more) for 1976-77 showed 176 percent more events in the urban area than in the rural "control" (Changnon et al., 1979). Hence, urban-induced increases in rainfall are responsible for 14 to 176 percent more heavy rain events in Chicago. There are 10 to 100 percent more flooding events in urban areas than in rural areas (Changnon, 1980). But the data also suggest an urban-related decrease in rainfall during cold fronts and light rain events (Changnon et al., 1979).

In summary, there is urban-induced increase in rainfall in the Chicago area, and it is increasing with time. There is substantial spatial variability in precipitation, with greatest rainfall over the city center. The Illinois State Water Survey is operating a dense network of raingage throughout Chicago that is producing more consistent and accurate data on rainfall patterns than was previously available (Peppler, 1991). Finally, urban-induced rainfall increases flooding in the Chicago area and inflates costs for flood control, insurance, and property damage.

Flood Control

Flooding has been an historic problem in the Chicago area. Poorly draining soils, little topographic relief, and old combined sewer systems intended to carry both sanitary and storm flows contribute to flooding during heavy rainfall events. The inadequacy of overburdened sewers results in back-ups in yards, basements, and Lake Michigan. These back-ups can pose health hazards as well as threaten property. Management approaches range from the highly technological to the more traditional solutions used in cities throughout the country.

The Metropolitan Water Reclamation District of Greater Chicago (MWRD) has a history of finding innovative solutions to difficult hydrologic problems. The Tunnel and Reservoir Project (TARP), one of the most ambitious public works projects ever undertaken, is one example. The TARP concept is to store water and sewage in 35-foot-wide (10.6 meters) tunnels located 300 feet (91 meters) underground, and then send it through existing treatment plants. The Mainstream Tunnel System was completed in 1985, stores 1 billion gallons (3.8 billion liters) of water, and has eliminated 80 percent of the combined sewage pollution throughout most of Chicago and its 15 suburbs (Robinson, 1986). Phase II, now

under construction, will include additional tunnel systems and reservoirs. Because the cost of TARP is high (about $1 billion for the Mainstream Tunnel), some communities have adopted lower cost alternatives.

The Village of Skokie's Flood Relief Program illustrates solutions that are proving to be cost-effective in suburban areas. The program uses inlet control technology to restrict flow off streets into sewers, thus reducing basement flooding. Roadway berms and flow-regulators attached to sewer inlets cause water to temporarily pond on streets. Off-street storage tanks also detain the drainage flow until sewers can accept it. The program is funded by property taxes with an estimated cost to the average homeowner of $100 per year (Village of Skokie, 1991).

The MWRD and most suburban communities have ordinances that require separate sanitary and storm sewer systems, as well as detention of runoff. Stormwater detention basins are commonplace in newer shopping centers, business parks, housing developments, and other types of intensive land uses. The design goal of most on-site basins is to meter runoff so that postdevelopment rates do not exceed predevelopment rates. Comprehensive planning for regional flood control has been sought but not implemented due to the diverse interests of local governments.

Lake Michigan Diversion Issues

Chicago obtained drinking water from Lake Michigan beginning in 1840. Continued unregulated water use by Chicago and its suburbs led to a law suit by surrounding states. After years of hearings, the court decided to set an allowable diversion rate and later approved a flexible accounting system that recognizes long-term climate and urban influences on weather (Changnon, 1981). For example, the urban runoff allotment recognizes the degree to which urbanization is increasing runoff by heavier urban rainfall and larger areas covered by impervious surfaces. The probability of occasional 2-year periods of drought also is accommodated.

The new allotments provide larger amounts of water for domestic purposes than before. Growing suburban communities are purchasing treated lake water from Chicago because demand has outstripped the supply of local wells. Sprinkling bans, severely depleted groundwater aquifers, and cheap water will be things of the past for the 23 DuPage County suburbs that plan to use only lake water by May 1, 1992 (Ritter, 1992). The DuPage Water Commission will buy an average of 110 gallons (416 liters) per capita per day and charge municipalities $1.95 per 1,000 gallons ($0.52 per kiloliters). This rate will make DuPage water among the most expensive in the United States, and could spur efforts to conserve landscape water.

7 CUFCP RESEARCH

Chicago's urban greenspace is a valuable resource that contributes to residents' quality of life. The preceding discussion has identified and reviewed a number of environmental issues of special importance in Chicago. Its existing urban forest is helping cool the city, cleanse the air, conserve energy, limit emissions of CO_2, and reduce stormwater runoff and flooding. It provides many other benefits as well, such as opportunities for recreation and relaxation, wildlife habitat, increased property values, and more attractive streets, parks, neighborhoods, and communities. However, there is substantial potential for additional benefits.

The following section summarizes CUFCP objectives and research plan. A companion document to this report entitled "Study Plans for the Chicago Urban Forest Climate Project" contains detailed descriptions of each proposed research project.

CUFCP GOALS AND OBJECTIVES

The goal of the CUFCP is to develop information that can be used by greenspace managers, natural resource planners, utilities, and residents to obtain greater benefit from Chicago's urban forest. Specifically, the project's aim is to:

1) Enhance our understanding of relations between urban greenspace and other aspects of Chicago's physical environment including its hydroclimate, air quality, energy use, and carbon cycling.

2) Determine the net benefits of greenspace by translating selected environmental benefits into dollar terms and accounting for vegetation management costs.

3) Produce recommendations on greenspace management that demonstrate how the selection, location, planting, and management of trees and similar resources can maximize net environmental benefits.

4) Develop new approaches for understanding urban forest structure and function that can be applied in other communities across the United States.

CUFCP RESEARCH APPROACH

CUFCP analyses and recommendations will be conducted at both the regional and neighborhood level. Regional findings on the effects of existing vegetation and proposed future plantings on air quality, CO_2, and other benefits and costs will be presented for the City of Chicago, Cook County (excluding Chicago), and DuPage County. Thus, each jurisdiction will have results that are specific to the types of urban forest and development patterns that are unique to that area. These findings are likely to be of most value to policymakers, regional planners, municipal/county greenspace managers, and other researchers dealing with regional air, water, and energy issues.

Research at the neighborhood level will seek to better understand relations between greenspace and neighborhood hydroclimates, energy use patterns, and carbon cycling by studying one or more residential neighborhoods in detail. Inventories, measurements, models, analyses, and recommendations will be more specific and refined at this level than at the regional level. A more precise resolution is required at the neighborhood level because greenspace benefits are significantly affected by the actions of residents and professional landscapers on individual properties. Findings from the neighborhood research will be of particular interest to local utilities, landscape professionals, and homeowners.

CUFCP RESEARCH COMPONENTS

Detailed study plans have been developed by CUFCP scientists and are contained in a companion document. A brief description of each research component follows.

1. Determining Urban Forest Structure Using Aerial Photographs and Ground Surveys (David Nowak, USDA Forest Service)

This study's objective is to determine the distribution of land use types, and tree cover, species, and physical attributes of trees and other vegetation by land use type. The study will be conducted in two stages: Stage 1 will sample aerial photographs; Stage 2 will include ground sampling of vegetation that incorporates points from Stage 1 photo sampling to determine locations of ground plot.

2. Demonstration of the Use of Airborne Video for Determining Urban Forest Structure and Health (Greg McPherson, USDA Forest Service, and Ross Pywell, USDA Forest Service-Methods Application Group)

The objective of this study is to determine if airborne videography is a cost-effective means of obtaining information on urban forest structure and health compared to the use of traditional aerial photo interpretation and field sampling. If so, guidelines for its use in urban environments will be developed.

3. Urban Tree Leaf Area, Leaf Biomass, and Growth Rates (David Nowak and Greg McPherson)

The objectives of this study are to determine which methods yield non-biased estimates of leaf-area index; estimate total leaf area and leaf biomass by species or genera in Chicago, and determine age-d.b.h. relations of common urban tree species. Additionally, annual growth rates of urban trees will be determined by tree-ring analysis. These data will be used with other information on urban forest structure to model impacts of existing and planned plantings on environmental variables such as air quality and climate.

4. Urban Hydroclimatological Flux Study: Measurement and Modeling (Sue Grimmond, Indiana University)

This study will investigate through field measurements the size of the energy balance fluxes in selected Chicago-area neighborhoods. These data will be used to evaluate the performance of the Grimmond and Oke evaporation-interception model, and to simplify the model for use with routinely collected meteorological measurements. The model will be applied to investigate the influence of urban forest structure on energy and water exchange.

5. Prediction of Urban Forest Effects on the Sub-Canopy Microclimate (Gordon Heisler, USDA Forest Service, Rich Grant, Purdue University, and Catherine Souch, Indiana University)

The objective of this study is to develop empirical models of urban forest effects on hourly averaged windspeed, air temperature, and humidity. The models will be based on climatic measurements in the open and at locations representative of different urban forest densities. Once developed and validated, the model will be used to help predict the effects of urban vegetation on energy use in Chicago residential buildings.

6. Modeling Urban Forest Effects on Building Energy Use (Gordon Heisler and Greg McPherson)

This study will determine the effects of existing urban vegetation on residential energy use in selected Chicago neighborhoods. Computer modeling will be used to identify optimal tree locations and species for energy savings in these neighborhoods, as well as their cost-effectiveness. Effects of different urban forest management strategies will be simulated over a 30-year period to evaluate the flow of energy savings over the long term.

7. Modeling Urban Forest Effects on Atmospheric Pollutants (David Nowak)

The objective of this study is to model the effect of present vegetation and of increasing and decreasing amounts of vegetation on particulate pollutants, SO_2, NO_x, CO, and O_3. The model will use information on urban forest structure, pollution absorption rates by vegetation, urban climate, and pollution concentrations to project vegetation effects at regional and neighborhood levels.

8. Modeling Urban Forest Effects on Atmospheric Carbon Dioxide (David Nowak)

This study will quantify present and estimate future amounts of carbon stored and avoided by urban trees. Tree biomass and carbon storage will be estimated on the basis of information collected from field plots. Avoided carbon emissions from power plants will be determined from work done to estimate the effects of the urban forest on energy use for space cooling and heating.

9. Modeling Benefits and Costs of Urban Forest Plantings and Management in Chicago (Greg McPherson)

This study will integrate results from other studies (e.g., hydroclimate, air

quality, energy use, and carbon storage) to determine the tangible and intangible benefits and costs associated with selected urban forest management activities. Benefits and costs will be projected for planned plantings in Chicago, as well as for tree planting, pruning, removal, and replacement at the neighborhood level.

It should be recognized that the course of research may deviate from that proposed here in response to changes in personnel, funding, and new information. For additional information regarding CUFCP research contact individual scientists or the Project at (312) 539-1973.

APPENDIX A

AIR POLLUTION MITIGATION BY TREES IN LINCOLN PARK

Trees mitigate air pollution through particulate interception and absorption of gases. The following section estimates the quantity of pollutants removed from the air by trees in a portion of Lincoln Park and suggests an implied annual air pollution mitigation value for trees in the Lincoln Park study area.

EFFECTS ON AIR POLLUTION

The interception of particulate matter and the absorption of sulfur dioxide (SO_2), carbon monoxide (CO), and nitrogen oxides (NO_x) are approximated from an analysis of tree cover and assumptions and estimates derived from the literature. Methodology for this analysis was derived from DeSanto et al. (1976). There is limited information on pollution interception and absorption rates by trees and these Lincoln Park figures should be considered "best guess" and likely maximum estimates. This section has not been subject to outside review and thus should be considered preliminary.

Study Area

The area of analysis is approximately 525 acres (212 hectares) in Lincoln Park between Wilson Drive and Fullerton Avenue. Tree cover in this area was estimated using random dot grid sampling of 1987 aerial photographs. Tree cover is estimated to be 23.2 percent (standard error = 2.2 percent; n = 379).

Leaf and Woody Area

To estimate interception and absorption rates for trees, it is necessary to have an estimate of total leaf and woody surface area. These surface areas are derived through leaf area and woody surface area indices which reveal the ratio of leaf and woody surface area relative to the ground area covered by the tree canopy. The leaf area index for Lincoln Park is assumed to be four, the woody surface area index = 1.7 (e.g., a tree that covers 10 m^2 of ground has 40 m^2 of leaf area and 17 m^2 of woody area). These indices are derived from conservative estimates of leaf and woody area indices for deciduous forests (Smith, 1981). Current studies are analyzing leaf and woody area indices for urban trees.

Interception and Absorption Rates

Estimates of interception and absorption flux rates for Lincoln Park trees are derived from average interception and absorption flux rates found in the literature (DeSanto et al., 1976). Interception and absorption flux rates are given in ug/m^2/hr: NO_x = 2,300; particulates = 2,500; CO = 2,600; and SO_2 = 41,000.

Particulates are intercepted all year long by woody surfaces and all day long by foliage during "in-leaf" season. Gaseous pollutants are absorbed via leaf stomates during "in-leaf" season when the stomates are open (i.e., daylight hours for non-stressed trees; fewer hours for stressed trees because stomates close during the day). Sulfur and nitrogen

dioxides are taken up by respiring leaves in the dark, but uptake rates are greatly reduced (Smith, 1981) and assumed to be negligible.

Water soluble gaseous pollutants (e.g., SO_2 and NO_2) can also be bound or dissolved on wet exterior plant surfaces. When plant surfaces are damp, pollutant removal rates may increase up to 10-fold (Smith, 1981).

All trees in Lincoln Park are assumed to be deciduous and dry (99.7 percent of the inventoried trees in Lincoln Park were deciduous species). Trees are assumed to be healthy and amply watered. Interception and absorption estimates given below are for a July day (stomates assumed to be open during 14.5 daylight hours).

Findings

Total leaf surface area: (0.232 = percent tree cover) (4 = leaf area index)

212 ha x 10,000 m^2/ha x 0.232 x 4 = 1,967,000 m^2

Total woody surface area: (0.232 = percent tree cover) (1.7 = woody area index)

212 ha x 10,000 m^2/ha x 0.232 x 1.7 = 836,000 m^2

Particulate Interception Rate:

Woody Tissue = 110 lb/day

2,500 ug/m^2/hr x 836,000 m^2 x 24 hr/day x (2.2 x 10^{-9} lb/ug)

Leafy Tissue = 260 lb/day

2,500 ug/m^2/hr x 1,967,000 m^2 x 24 hr/day x (2.2 x 10^{-9} lb/ug)

Total Tree Interception = 370 lb/day

Gaseous Pollutant Absorption Rates:

CO = 163 lb/day

2,600 ug/m^2/hr x 1,967,000 m^2 x 14.5 hr/day x (2.2 x 10^{-9} lb/ug)

NO_x = 144 lb/day

2,300 ug/m^2/hr x 1,967,000 m^2 x 14.5 hr/day x (2.2 x 10^{-9} lb/ug)

SO_2 = 2,573 lb/day

41,000 ug/m^2/hr x 1,967,000 m^2 x 14.5 hr/day x (2.2 x 10^{-9} lb/ug)

Summary of Effects on Air Pollution

These approximate interception and absorption estimates are based on average flux rates found in the literature. Actual flux rates vary with pollutant concentration and various plant and environmental factors. Many flux rates in the literature were determined at high pollution concentration levels, therefore absorption rates are likely near the maximum potential. Absorption of pollutants will likely decrease through time at high pollution concentrations as the tree becomes adversely affected by the pollutant and stomates close (e.g., SO_2, O_3) or leaves become encrusted with particulates. Estimated absorption rates will decrease as trees in Lincoln Park experience water stress. There are many problems and uncertainties in evaluating pollutant uptake using this methodology (DeSanto, 1976). However, results do yield the relative differences in uptake and potential magnitude of effect urban trees can have on air quality. Very limited research on air pollution uptake by urban trees has been conducted to date. Future research needs to evaluate pollution uptake by trees that is specific to urban environments.

IMPLIED VALUE OF AIR POLLUTION MITIGATION

By reducing air pollutants trees have a positive effect on human health and the environment. It is not possible to directly estimate the air cleansing value of these trees because of uncertainty regarding dose-response relationships between the pollutants and humans, effects of degraded health on health care costs, and the localized effects of trees on air pollution concentrations. Therefore, implied valuation is used to estimate a societal value of reducing residual air pollutants. The implied valuation technique uses the costs of traditional air pollution controls to provide direct information on the societal value of clean air. Control costs are assumed to estimate the price that society is willing to pay to reduce the pollutant. Hence, if society is willing to pay $2/lb for current or planned air pollution control, then a tree that intercepts or absorps a pound of pollution should also be worth $2.

Calculating Implied Values

The combined annual implied value of trees in the Lincoln Park study area is the sum across all pollutants of the following product:

Amount of each pollutant absorped/intercepted (in lb/day)	X	Unit value of that pollutant (in $/lb)

Due to the unavailability of data for Chicago and Illinois regarding air pollution control costs, 1990 estimates for the Northeast United States were used in this analysis (estimates made by the Tellus Institute and used as measurable average values for the United States). It should be recognized that these values may not accurately reflect the highest price Chicagoans are willing to pay to reduce various air pollutants at the margin.

Results

The implied annual air pollution mitigation value of trees in the Lincoln Park study area is shown in Table 1 for each pollutant. Greatest benefits are received from absorption of sulfur oxides (SO_x) ($2,007/day) and interception of particulates ($773/day). The total implied value for a July day is $3,343.

Table 1
Estimated Implied Values for Air Pollution Mitigation by
Trees in the Lincoln Park Study Area

Pollutants	Unit Value [1] $/lb	Reduction Rate lb/day	Implied Value $/day
Nitrogen Oxides	3.40	144	490
Sulfur Oxides	0.78	2,573	2,007
Total Particulates	2.09	370	773
Carbon monoxide	0.45	163	73
Total Implied Value			3,343

[1] 1990 estimates by the Tellus Institute for the N.E. U.S. and as measurable average values for the United States.

Even though pollutant uptake rates exhibited above are likely near a maximum, trees in the Lincoln Park study area are likely to have a considerably higher environmental value than shown in Table 1. Not included in this calculation are implied values for absorption of ozone (O_3) and carbon dioxide (CO_2), both air pollutants of first order importance. Additionally, as has been done in other studies, implied value could be ascribed to the trees' mitigating effects on hydrology (e.g., reduced runoff due to crown interception) and climate (e.g., heat island mitigation and associated reductions in air conditioning energy use, human thermal stress, and O_3 production).

[illegible]

[illegible] Table 1. We include [illegible] in this [illegible] [illegible]

[illegible]

APPENDIX B

LAND COVER BY COMMUNITY AREA

APPENDIX B

CHICAGO

Community Area No.		Street Tree	Managed Tree	Unmanaged Tree	Total Tree Cover	Street Grass	Managed Grass	Unmanaged Grass	Total Grass Cover	Building	Paved	Water
1	percent	7.90	4.57	0.21	12.68	0.83	13.72	0.62	15.18	38.46	33.68	0.00
	std error	1.23	0.95	0.21	1.52	0.41	1.57	0.36	1.64	2.22	2.15	0.00
2	percent	8.61	8.01	0.59	17.21	0.89	13.95	0.59	15.43	37.09	30.27	0.00
	std error	1.53	1.48	0.42	2.06	0.51	1.89	0.42	1.97	2.63	2.50	0.00
3	percent	2.54	9.89	0.28	12.71	1.13	24.58	0.85	26.55	29.10	31.64	0.00
	std error	0.84	1.59	0.28	1.77	0.56	2.29	0.49	2.35	2.41	2.47	0.00
4	percent	5.91	10.59	0.00	16.50	2.22	20.20	0.25	22.66	30.05	30.54	0.25
	std error	1.17	1.53	0.00	1.84	0.73	1.99	0.25	2.08	2.28	2.29	0.25
5	percent	8.31	5.75	0.32	14.38	1.92	16.29	2.56	20.77	34.82	29.07	0.96
	std error	1.56	1.32	0.32	1.98	0.78	2.09	0.89	2.29	2.69	2.57	0.55
6	percent	2.32	5.96	0.33	8.61	5.63	11.92	1.66	19.21	48.34	21.52	2.32
	std error	0.87	1.36	0.33	1.61	1.33	1.86	0.74	2.27	2.88	2.36	0.87
7	percent	1.94	6.13	0.32	8.39	3.23	16.77	2.26	22.26	36.13	28.39	4.84
	std error	0.78	1.36	0.32	1.57	1.00	2.12	0.84	2.36	2.73	2.56	1.22
8	percent	0.26	4.65	0.26	5.17	0.26	8.27	5.17	13.70	37.98	40.83	2.33
	std error	0.26	1.07	0.26	1.13	0.26	1.40	1.13	1.75	2.47	2.50	0.77
9	percent	12.58	8.61	0.00	21.19	3.31	14.57	0.00	17.88	33.77	27.15	0.00
	std error	1.91	1.61	0.00	2.35	1.03	2.03	0.00	2.20	2.72	2.56	0.00
10	percent	7.06	5.29	0.00	12.35	2.65	24.71	0.00	27.35	32.06	28.24	0.00
	std error	1.39	1.21	0.00	1.78	0.87	2.34	0.00	2.42	2.53	2.44	0.00
11	percent	5.82	3.44	4.50	13.76	3.44	16.67	0.00	20.11	30.95	35.19	0.00
	std error	1.20	0.94	1.07	1.77	0.94	1.92	0.00	2.06	2.38	2.46	0.00
12	percent	5.76	9.09	22.12	36.97	1.21	14.85	2.73	18.79	23.94	20.30	0.00
	std error	1.28	1.58	2.28	2.66	0.60	1.86	0.90	2.15	2.35	2.21	0.00
13	percent	2.84	13.14	11.34	27.32	1.03	25.52	0.77	27.32	21.13	23.45	0.77
	std error	0.84	1.72	1.61	2.26	0.51	2.21	0.44	2.26	2.07	2.15	0.44
14	percent	10.00	6.36	1.21	17.58	1.82	11.52	0.61	13.94	37.58	30.61	0.30
	std error	1.65	1.34	0.60	2.10	0.74	1.76	0.43	1.91	2.67	2.54	0.30
15	percent	5.19	2.92	0.32	8.44	3.57	13.64	0.00	17.21	41.23	33.12	0.00
	std error	1.26	0.96	0.32	1.58	1.06	1.96	0.00	2.15	2.80	2.68	0.00
16	percent	0.92	2.77	1.23	4.92	3.08	18.15	0.00	21.23	41.23	32.62	0.00
	std error	0.53	0.91	0.61	1.20	0.96	2.14	0.00	2.27	2.73	2.60	0.00
17	percent	2.96	4.58	1.62	9.16	5.12	25.88	0.81	31.81	36.66	22.37	0.00
	std error	0.88	1.09	0.66	1.50	1.14	2.27	0.47	2.42	2.50	2.16	0.00
18	percent	7.94	4.73	0.00	12.67	4.16	16.45	1.32	21.93	32.70	32.70	0.00
	std error	1.18	0.92	0.00	1.45	0.87	1.61	0.50	1.80	2.04	2.04	0.00
19	percent	5.67	2.00	0.00	7.67	2.33	17.67	0.33	20.33	39.67	32.33	0.00
	std error	1.34	0.81	0.00	1.54	0.87	2.20	0.33	2.32	2.82	2.70	0.00
20	percent	9.88	4.32	0.00	14.20	3.40	15.74	0.00	19.14	35.49	31.17	0.00
	std error	1.66	1.13	0.00	1.94	1.01	2.02	0.00	2.19	2.66	2.57	0.00
21	percent	6.97	2.73	0.30	10.00	1.21	10.61	0.61	12.42	36.06	40.00	1.52
	std error	1.40	0.90	0.30	1.65	0.60	1.70	0.43	1.82	2.64	2.70	0.67
22	percent	0.27	4.12	0.00	4.40	3.30	17.86	0.55	21.70	42.58	30.77	0.55
	std error	0.27	1.04	0.00	1.07	0.94	2.01	0.39	2.16	2.59	2.42	0.39
23	percent	0.58	2.88	0.29	3.75	5.76	20.75	2.59	29.11	38.04	29.11	0.00
	std error	0.41	0.90	0.29	1.02	1.25	2.18	0.85	2.44	2.61	2.44	0.00
24	percent	5.65	5.37	0.28	11.30	1.69	7.91	1.13	10.73	34.46	43.22	0.28
	std error	1.23	1.20	0.28	1.68	0.69	1.43	0.56	1.64	2.53	2.63	0.28
25	percent	5.65	8.00	0.24	13.88	2.12	16.47	0.71	19.29	26.82	39.76	0.24
	std error	1.12	1.32	0.24	1.68	0.70	1.80	0.41	1.91	2.15	2.37	0.24
26	percent	7.25	5.51	0.29	13.04	1.74	9.86	5.51	17.10	32.46	37.39	0.00
	std error	1.40	1.23	0.29	1.81	0.70	1.61	1.23	2.03	2.52	2.60	0.00
27	percent	3.06	8.56	0.61	12.23	1.53	13.46	10.40	25.38	26.61	35.17	0.61
	std error	0.95	1.55	0.43	1.81	0.68	1.89	1.69	2.41	2.44	2.64	0.43
28	percent	0.63	0.32	0.00	0.95	1.58	11.04	2.84	15.46	37.85	45.74	0.00
	std error	0.44	0.32	0.00	0.54	0.70	1.76	0.93	2.03	2.72	2.80	0.00
29	percent	0.98	5.23	0.33	6.54	4.58	16.34	6.21	27.12	35.95	29.74	0.65
	std error	0.56	1.27	0.33	1.41	1.20	2.11	1.38	2.54	2.74	2.61	0.46

CHICAGO

Community Area No.		Street Tree	Managed Tree	Unmanaged Tree	Total Tree Cover	Street Grass	Managed Grass	Unmanaged Grass	Total Grass Cover	Building	Paved	Water
30	percent	5.14	1.08	0.00	6.22	1.35	17.57	6.22	25.14	26.22	39.46	2.97
	std error	1.15	0.54	0.00	1.26	0.60	1.98	1.26	2.26	2.29	2.54	0.88
31	percent	0.00	1.31	0.00	1.31	0.33	19.28	0.33	19.93	29.74	44.12	4.90
	std error	0.00	0.65	0.00	0.65	0.33	2.26	0.33	2.28	2.61	2.84	1.23
32	percent	0.73	1.94	4.84	7.51	0.00	10.65	8.47	19.13	32.45	36.08	4.84
	std error	0.42	0.68	1.06	1.30	0.00	1.52	1.37	1.94	2.30	2.36	1.06
33	percent	0.00	3.47	0.61	4.08	0.82	18.98	7.35	27.14	18.57	44.69	5.51
	std error	0.00	0.83	0.35	0.89	0.41	1.77	1.18	2.01	1.76	2.25	1.03
34	percent	1.67	1.11	0.74	3.53	0.37	11.13	2.04	13.54	20.78	60.48	1.67
	std error	0.55	0.45	0.37	0.79	0.26	1.35	0.61	1.47	1.75	2.11	0.55
35	percent	0.00	5.56	4.22	9.78	0.44	32.22	0.67	33.33	18.00	38.44	0.44
	std error	0.00	1.08	0.95	1.40	0.31	2.20	0.38	2.22	1.81	2.29	0.31
36	percent	0.98	5.25	0.33	6.56	0.00	33.77	8.85	42.62	10.82	40.00	0.00
	std error	0.56	1.28	0.33	1.42	0.00	2.71	1.63	2.83	1.78	2.81	0.00
37	percent	1.77	4.55	1.52	7.83	0.76	11.87	6.57	19.19	16.41	56.57	0.00
	std error	0.66	1.05	0.61	1.35	0.44	1.63	1.25	1.98	1.86	2.49	0.00
38	percent	4.33	3.30	0.21	7.84	2.68	16.08	10.52	29.28	23.71	39.18	0.00
	std error	0.92	0.81	0.21	1.22	0.73	1.67	1.39	2.07	1.93	2.22	0.00
39	percent	1.66	8.69	0.55	10.91	2.40	24.58	4.44	31.42	20.15	37.52	0.00
	std error	0.55	1.21	0.32	1.34	0.66	1.85	0.89	2.00	1.72	2.08	0.00
40	percent	0.27	5.42	10.57	16.26	2.17	27.10	5.42	34.69	26.02	21.41	1.63
	std error	0.27	1.18	1.60	1.92	0.76	2.31	1.18	2.48	2.28	2.14	0.66
41	percent	4.73	7.21	0.45	12.39	1.13	23.87	0.23	25.23	23.65	37.39	1.35
	std error	1.01	1.23	0.32	1.56	0.50	2.02	0.23	2.06	2.02	2.30	0.55
42	percent	5.67	9.32	0.37	15.36	1.28	21.39	7.68	30.35	22.30	27.61	4.39
	std error	0.99	1.24	0.26	1.54	0.48	1.75	1.14	1.97	1.78	1.91	0.88
43	percent	6.01	8.80	0.86	15.67	1.72	17.60	3.43	22.75	31.97	28.61	0.00
	std error	1.10	1.31	0.43	1.68	0.60	1.76	0.84	1.94	2.16	2.11	0.00
44	percent	10.28	5.35	1.50	17.13	1.50	15.63	0.00	17.13	26.98	38.76	0.00
	std error	1.41	1.04	0.56	1.74	0.56	1.68	0.00	1.74	2.05	2.25	0.00
45	percent	7.21	6.43	0.78	14.42	1.88	18.81	0.47	21.16	23.20	41.22	0.00
	std error	1.02	0.97	0.35	1.39	0.54	1.55	0.27	1.62	1.67	1.95	0.00
46	percent	1.96	1.31	0.98	4.25	3.92	22.22	4.58	30.72	35.95	27.45	1.63
	std error	0.79	0.65	0.56	1.15	1.11	2.38	1.20	2.64	2.74	2.55	0.72
47	percent	4.52	4.19	2.26	10.97	0.97	20.65	9.35	30.97	20.32	37.74	0.00
	std error	1.18	1.14	0.84	1.77	0.56	2.30	1.65	2.63	2.29	2.75	0.00
48	percent	7.11	4.22	2.00	13.33	1.33	12.00	2.67	16.00	31.11	39.56	0.00
	std error	1.21	0.95	0.66	1.60	0.54	1.53	0.76	1.73	2.18	2.31	0.00
49	percent	6.61	8.82	1.65	17.08	3.58	25.07	2.48	31.13	21.21	30.58	0.00
	std error	1.30	1.49	0.67	1.98	0.98	2.27	0.82	2.43	2.15	2.42	0.00
50	percent	4.12	3.24	6.18	13.53	0.59	30.59	8.53	39.71	21.76	24.41	0.59
	std error	1.08	0.96	1.31	1.85	0.42	2.50	1.51	2.65	2.24	2.33	0.42
51	percent	0.00	0.56	7.25	7.81	0.56	25.84	14.50	40.89	9.48	23.05	18.77
	std error	0.00	0.32	1.12	1.16	0.32	1.89	1.52	2.12	1.26	1.82	1.68
52	percent	0.64	5.47	1.29	7.40	3.54	24.44	6.75	34.73	22.51	26.69	8.68
	std error	0.45	1.29	0.64	1.48	1.05	2.44	1.42	2.70	2.37	2.51	1.60
53	percent	6.77	7.42	2.58	16.77	2.26	17.74	5.16	25.16	31.94	24.52	1.61
	std error	1.43	1.49	0.90	2.12	0.84	2.17	1.26	2.46	2.65	2.44	0.71
54	percent	0.65	0.97	5.81	7.42	0.00	41.29	2.90	44.19	6.13	30.32	11.94
	std error	0.46	0.56	1.33	1.49	0.00	2.80	0.95	2.82	1.36	2.61	1.84
55	percent	0.58	1.46	18.95	20.99	1.75	27.70	11.66	41.11	8.75	14.29	14.87
	std error	0.41	0.65	2.12	2.20	0.71	2.42	1.73	2.66	1.53	1.89	1.92
56	percent	4.98	2.66	0.33	7.97	1.66	23.92	1.99	27.57	25.25	38.54	0.66
	std error	1.25	0.93	0.33	1.56	0.74	2.46	0.80	2.58	2.50	2.81	0.47
57	percent	2.17	0.31	0.00	2.48	2.48	13.31	0.62	16.41	34.06	47.06	0.00
	std error	0.81	0.31	0.00	0.87	0.87	1.89	0.44	2.06	2.64	2.78	0.00
58	percent	0.66	2.99	0.00	3.65	4.65	14.95	1.66	21.26	39.53	35.55	0.00
	std error	0.47	0.98	0.00	1.08	1.21	2.06	0.74	2.38	2.82	2.76	0.00

APPENDIX B

CHICAGO

Community Area No.		Street Tree	Managed Tree	Unmanaged Tree	Total Tree Cover	Street Grass	Managed Grass	Unmanaged Grass	Total Grass Cover	Building	Paved	Water
59	percent	6.75	5.71	0.78	13.25	1.30	9.09	2.86	13.25	26.75	46.23	0.52
	std error	1.28	1.18	0.45	1.73	0.58	1.47	0.85	1.73	2.26	2.54	0.37
60	percent	2.52	2.24	0.00	4.76	0.84	13.73	2.80	17.37	37.25	38.38	2.24
	std error	0.83	0.78	0.00	1.13	0.48	1.82	0.87	2.01	2.56	2.57	0.78
61	percent	3.95	1.32	0.53	5.79	1.05	11.05	5.79	17.89	24.74	50.79	0.79
	std error	1.00	0.59	0.37	1.20	0.52	1.61	1.20	1.87	2.21	2.56	0.45
62	percent	4.38	2.50	0.31	7.19	4.69	20.31	0.63	25.63	33.44	33.75	0.00
	std error	1.14	0.87	0.31	1.44	1.18	2.25	0.44	2.44	2.64	2.64	0.00
63	percent	5.25	2.21	0.28	7.73	3.04	18.78	0.55	22.38	35.64	34.25	0.00
	std error	1.17	0.77	0.28	1.40	0.90	2.05	0.39	2.19	2.52	2.49	0.00
64	percent	2.65	1.93	0.24	4.82	3.37	22.65	0.72	26.75	25.30	43.13	0.00
	std error	0.79	0.68	0.24	1.05	0.89	2.05	0.42	2.17	2.13	2.43	0.00
65	percent	0.62	1.87	0.62	3.12	5.30	23.68	1.56	30.53	33.02	33.33	0.00
	std error	0.44	0.76	0.44	0.97	1.25	2.37	0.69	2.57	2.62	2.63	0.00
66	percent	5.59	6.15	0.28	12.01	1.68	18.99	0.28	20.95	34.08	30.45	2.51
	std error	1.21	1.27	0.28	1.72	0.68	2.07	0.28	2.15	2.51	2.43	0.83
67	percent	1.62	2.60	2.60	6.82	7.14	19.16	6.49	32.79	31.82	28.57	0.00
	std error	0.72	0.91	0.91	1.44	1.47	2.24	1.40	2.67	2.65	2.57	0.00
68	percent	1.99	1.32	0.99	4.30	4.30	24.83	1.99	31.13	29.47	35.10	0.00
	std error	0.80	0.66	0.57	1.17	1.17	2.49	0.80	2.66	2.62	2.75	0.00
69	percent	1.51	6.93	1.81	10.24	5.42	21.39	4.52	31.33	27.11	31.33	0.00
	std error	0.67	1.39	0.73	1.66	1.24	2.25	1.14	2.55	2.44	2.55	0.00
70	percent	4.43	5.70	3.80	13.92	1.90	25.32	0.00	27.22	25.00	33.86	0.00
	std error	1.16	1.30	1.08	1.95	0.77	2.45	0.00	2.50	2.44	2.66	0.00
71	percent	2.50	3.33	5.28	11.11	6.94	18.61	2.78	28.33	39.72	20.83	0.00
	std error	0.82	0.95	1.18	1.66	1.34	2.05	0.87	2.37	2.58	2.14	0.00
72	percent	3.82	11.78	14.65	30.25	7.96	21.02	0.00	28.98	19.43	21.34	0.00
	std error	1.08	1.82	2.00	2.59	1.53	2.30	0.00	2.56	2.23	2.31	0.00
73	percent	8.91	9.90	0.99	19.80	3.30	21.45	0.66	25.41	23.76	31.02	0.00
	std error	1.64	1.72	0.57	2.29	1.03	2.36	0.47	2.50	2.45	2.66	0.00
74	percent	3.98	9.13	0.00	13.11	2.34	35.36	1.87	39.58	25.53	21.55	0.23
	std error	0.95	1.39	0.00	1.63	0.73	2.31	0.66	2.37	2.11	1.99	0.23
75	percent	2.10	9.61	5.41	17.12	6.31	27.33	0.60	34.23	20.42	28.23	0.00
	std error	0.79	1.62	1.24	2.06	1.33	2.44	0.42	2.60	2.21	2.47	0.00
76	percent	0.00	0.28	10.76	11.05	0.28	50.14	0.28	50.71	2.55	34.84	0.85
	std error	0.00	0.28	1.65	1.67	0.28	2.66	0.28	2.66	0.84	2.54	0.49
77	percent	7.71	4.28	0.00	11.99	1.50	13.49	0.00	14.99	40.04	32.98	0.00
	std error	1.23	0.94	0.00	1.50	0.56	1.58	0.00	1.65	2.27	2.18	0.00
115	percent	2.66	14.20	0.00	16.86	2.07	26.63	0.00	28.70	30.47	23.96	0.00
	std error	0.88	1.90	0.00	2.04	0.77	2.40	0.00	2.46	2.50	2.32	0.00
Weighted	percent	3.51	4.60	2.97	11.09	2.45	21.34	3.09	26.89	27.44	32.41	2.18
Average	std error	0.12	0.13	0.14	0.21	0.10	0.29	0.12	0.31	0.28	0.32	0.11

COOK

Community Area No.		Street Tree	Managed Tree	Unmanaged Tree	Total Tree Cover	Street Grass	Managed Grass	Unmanaged Grass	Total Grass Cover	Building	Paved	Water
78	percent	9.58	11.25	0.63	21.46	1.88	26.88	0.00	28.75	20.21	28.96	0.63
	std error	1.34	1.44	0.36	1.87	0.62	2.02	0.00	2.07	1.83	2.07	0.36
79	percent	5.53	19.15	5.96	30.64	3.62	33.40	0.00	37.02	14.04	17.02	1.28
	std error	1.05	1.81	1.09	2.13	0.86	2.18	0.00	2.23	1.60	1.73	0.52
80	percent	1.13	13.28	16.10	30.51	0.56	37.01	2.26	39.83	7.34	20.62	1.69
	std error	0.56	1.80	1.95	2.45	0.40	2.57	0.79	2.80	1.39	2.15	0.69
81	percent	3.49	11.05	6.98	21.51	1.74	37.21	1.45	40.41	13.08	22.97	2.03
	std error	0.99	1.69	1.37	2.22	0.70	2.61	0.64	2.65	1.82	2.27	0.76

COOK

Community Area No.		Street Tree	Managed Tree	Unmanaged Tree	Total Tree Cover	Street Grass	Managed Grass	Unmanaged Grass	Total Grass Cover	Building	Paved	Water
82	percent	0.59	9.38	10.58	20.82	1.47	42.23	5.87	49.56	10.85	15.84	2.93
	std error	0.41	1.58	1.68	2.20	0.65	2.67	1.27	2.71	1.68	1.98	0.91
83	percent	0.00	3.31	20.99	24.31	0.00	43.65	19.06	62.71	1.66	7.73	3.59
	std error	0.00	0.94	2.14	2.25	0.00	2.61	2.06	2.54	0.67	1.40	0.98
84	percent	0.00	6.45	16.13	22.58	1.08	53.33	9.89	64.30	3.87	8.17	1.08
	std error	0.00	1.14	1.71	1.94	0.48	2.31	1.38	2.22	0.89	1.27	0.48
85	percent	0.73	7.02	5.57	13.32	2.91	39.95	8.47	51.33	14.29	19.13	1.94
	std error	0.42	1.26	1.13	1.67	0.83	2.41	1.37	2.48	1.72	1.94	0.68
86	percent	1.29	3.10	9.04	13.44	1.03	27.13	9.30	37.47	21.19	24.55	3.36
	std error	0.57	0.88	1.46	1.73	0.51	2.26	1.48	2.48	2.08	2.19	0.92
87	percent	1.96	4.47	12.85	19.27	3.91	23.74	1.12	28.77	27.09	23.46	1.40
	std error	0.73	1.09	1.77	2.08	1.02	2.25	0.56	2.39	2.35	2.24	0.62
88	percent	1.76	12.90	10.85	25.51	2.05	25.22	0.59	27.86	24.05	22.58	0.00
	std error	0.71	1.82	1.68	2.36	0.77	2.35	0.41	2.43	2.31	2.26	0.00
89	percent	1.55	5.54	7.32	14.41	1.55	22.39	2.44	26.39	26.61	31.71	0.89
	std error	0.58	1.08	1.23	1.65	0.58	1.96	0.73	2.08	2.08	2.19	0.44
90	percent	4.76	12.61	10.08	27.45	1.96	21.29	2.80	26.05	17.09	29.13	0.28
	std error	1.13	1.76	1.59	2.36	0.73	2.17	0.87	2.32	1.99	2.40	0.28
91	percent	7.73	5.85	0.00	13.58	4.92	15.22	0.00	20.14	34.43	31.85	0.00
	std error	1.29	1.14	0.00	1.66	1.05	1.74	0.00	1.94	2.30	2.25	0.00
92	percent	2.64	2.64	2.31	7.59	1.65	30.69	3.96	36.30	13.86	37.95	4.29
	std error	0.92	0.92	0.86	1.52	0.73	2.65	1.12	2.76	1.99	2.79	1.16
93	percent	0.81	11.92	9.21	21.95	0.54	34.15	4.07	38.75	12.47	21.41	5.42
	std error	0.47	1.69	1.51	2.15	0.38	2.47	1.03	2.54	1.72	2.14	1.18
94	percent	0.00	1.17	36.84	38.01	0.29	37.43	8.19	45.91	2.05	8.48	5.56
	std error	0.00	0.58	2.61	2.62	0.29	2.62	1.48	2.69	0.77	1.51	1.24
95	percent	0.75	5.47	42.04	48.26	0.00	24.13	6.72	30.85	6.47	10.95	3.48
	std error	0.43	1.13	2.46	2.49	0.00	2.13	1.25	2.30	1.23	1.56	0.91
96	percent	2.57	14.95	5.37	22.90	2.10	25.23	5.61	32.94	17.52	25.47	1.17
	std error	0.76	1.72	1.08	2.03	0.69	2.10	1.11	2.27	1.84	2.11	0.52
97	percent	3.56	5.93	6.82	16.32	2.37	27.30	4.45	34.12	15.13	27.89	6.53
	std error	1.01	1.29	1.37	2.01	0.83	2.43	1.12	2.58	1.95	2.44	1.35
98	percent	5.32	4.65	9.30	19.27	0.66	25.58	13.62	39.87	14.62	24.92	1.33
	std error	1.29	1.21	1.67	2.27	0.47	2.51	1.98	2.82	2.04	2.49	0.66
99	percent	1.82	1.82	14.55	18.18	1.30	31.43	7.79	40.52	16.36	23.12	1.82
	std error	0.68	0.68	1.80	1.97	0.58	2.37	1.37	2.50	1.89	2.15	0.68
100	percent	1.06	9.04	17.82	27.93	0.53	36.44	9.57	46.54	8.78	15.96	0.80
	std error	0.53	1.48	1.97	2.31	0.37	2.48	1.52	2.57	1.46	1.89	0.46
101	percent	0.00	3.17	8.47	11.64	0.53	60.85	8.47	69.84	6.88	9.26	2.38
	std error	0.00	0.90	1.43	1.65	0.37	2.51	1.43	2.36	1.30	1.49	0.78
102	percent	0.58	0.86	13.26	14.70	0.86	59.65	12.97	73.49	4.90	6.92	0.00
	std error	0.41	0.50	1.82	1.90	0.50	2.63	1.80	2.37	1.16	1.36	0.00
103	percent	0.49	8.82	15.20	24.51	1.47	45.34	7.11	53.92	8.82	12.25	0.49
	std error	0.35	1.40	1.78	2.13	0.60	2.46	1.27	2.47	1.40	1.62	0.35
104	percent	0.33	1.67	7.33	9.33	0.00	73.33	4.33	77.67	6.33	5.33	1.33
	std error	0.33	0.74	1.50	1.68	0.00	2.55	1.18	2.40	1.41	1.30	0.66
116	percent	1.21	7.27	0.20	8.69	1.82	26.67	3.43	31.92	25.25	34.14	0.00
	std error	0.49	1.17	0.20	1.27	0.60	1.99	0.82	2.10	1.95	2.13	0.00
117	percent	2.72	5.69	11.14	19.55	1.73	30.69	2.48	34.90	14.11	31.44	0.00
	std error	0.81	1.15	1.57	1.97	0.65	2.29	0.77	2.37	1.73	2.31	0.00
Weighted Average	percent	1.60	7.50	13.44	22.54	1.36	36.77	6.58	44.71	12.58	18.24	1.93
	std error	0.13	0.28	0.36	0.44	0.12	0.50	0.27	0.51	0.34	0.40	0.15

DUPAGE

Community Area No.		Street Tree	Managed Tree	Unmanaged Tree	Total Tree Cover	Street Grass	Managed Grass	Unmanaged Grass	Total Grass Cover	Building	Paved	Water
105	percent	0.22	3.55	11.53	15.30	1.11	33.70	9.31	44.12	17.52	22.17	0.89
	std error	0.22	0.87	1.50	1.70	0.49	2.23	1.37	2.34	1.79	1.98	0.44
106	percent	0.59	1.78	6.90	9.27	3.16	46.15	15.19	64.50	10.06	13.02	3.16
	std error	0.34	0.59	1.13	1.29	0.78	2.21	1.59	2.13	1.34	1.49	0.78
107	percent	0.00	2.36	8.14	10.49	0.21	62.31	16.27	78.80	3.43	5.35	1.93
	std error	0.00	0.70	1.27	1.42	0.21	2.24	1.71	1.89	0.84	1.04	0.64
108	percent	1.08	1.89	16.76	19.73	0.00	52.70	12.97	65.68	3.51	7.30	3.78
	std error	0.54	0.71	1.94	2.07	0.00	2.60	1.75	2.47	0.96	1.35	0.99
109	percent	0.97	19.15	9.28	29.40	1.16	43.33	3.29	47.78	7.35	13.15	2.32
	std error	0.43	1.73	1.28	2.00	0.47	2.18	0.78	2.20	1.15	1.49	0.66
110	percent	1.46	5.85	14.91	22.22	2.34	30.99	7.02	40.35	15.79	19.88	1.75
	std error	0.65	1.27	1.93	2.25	0.82	2.50	1.38	2.85	1.97	2.16	0.71
111	percent	2.11	6.07	15.04	23.22	1.85	36.15	2.11	40.11	17.68	18.47	0.53
	std error	0.74	1.23	1.84	2.17	0.69	2.47	0.74	2.52	1.96	1.99	0.37
112	percent	0.20	2.55	15.29	18.04	1.96	45.88	7.65	55.49	8.43	16.67	1.37
	std error	0.20	0.70	1.59	1.70	0.61	2.21	1.18	2.20	1.23	1.65	0.51
113	percent	0.00	3.81	4.63	8.45	0.27	67.30	6.27	73.84	4.36	11.17	2.18
	std error	0.00	1.00	1.10	1.45	0.27	2.45	1.27	2.29	1.07	1.64	0.76
114	percent	0.00	5.36	31.10	36.46	0.54	28.69	9.12	38.34	9.12	13.94	2.14
	std error	0.00	1.17	2.40	2.49	0.38	2.34	1.49	2.52	1.49	1.79	0.75
Weighted	percent	0.64	5.20	12.80	18.64	1.26	45.63	9.14	56.03	9.40	13.88	2.08
Average	std error	0.13	0.32	0.47	0.55	0.17	0.73	0.43	0.71	0.43	0.51	0.22

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